VŠB – TECHNICAL UNIVERSITY OF OSTRAVA
FACULTY OF ECONOMICS

DEPARTMENT OF FINANCE

Možnosti zajištění finančního rizika ve společnosti BorsodChem MCHZ, s.r.o.

Financial risk hedging possibilities in BorsodChem MCHZ, s.r.o.

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I declare on word of honour that this piece of work including all the supplements is my own unaided effort.

In Ostrava on 22nd April 2010

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Petra Spáčilová

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1 Introduction

I'm not afraid of storms, for I'm learning how to sail my ship.
Louisa May Alcott

Everyone faces the risk. Risks are integrated part of decision making of either personal or legal entities. It can exist in different forms but all the time it is bounded with future uncertainty whereas it can be with good or bad result in the end.

Those risks for economical subjects are called financial risk and they have different forms as well. Financial markets represent place where financial risk is distributed between individual members. Subject who wants to quit this risk is switching it on subjects willing to take this risk with the help of different instruments.

BorsodChem company is successful company within chemical industry. Due to financial crisis has to face and manage several risks but mainly exchange rate risk. Most of the company's revenues flow from foreign countries and it is necessary to solve the problem of exchange rate volatility. It is not easy to forecast evolution of exchange rate and there are plenty of theories trying to explain it. The problem is that it is not only one factor causing volatility but whole package of factors which are occurring in global economy. Knowing this fact it is obvious that company has to protect themselves somehow.

There are many ways how we can eliminate or remove the risk. Financial derivatives usage is the most common way how to do that. Except from common forward contracts, swap contracts and option contracts there is wide choice of their modifications and combinations while in the same moment there are still accruing new ones in financial markets.

Goal of this thesis is to describe, analyze, apply and verify chosen hedging strategies which can be used for financial hedging in chemical company. Thesis is focused on currency risk hedging in Euro and US dollar trading.

Whole thesis is divided into three parts. The second chapter gives reader clear idea of BorsodChem MCHZ, s.r.o. company business. There is described its history, commercial policy, business relations and plans.

The third chapter is devoted to theoretical facts and principles necessary for this thesis. In the beginning there are defined financial risks and derivatives and their composition. It is especially focused on forward contracts, options (plain vanilla and exotic) and option strategies. There is described the characteristics of simulation Monte Carlo and a pricing of financial derivatives according to Black-Scholes and Garman-Kohlhagen model.

Last chapter is the practical part of this thesis where are applied chosen hedging strategies. Effect of those strategies is evaluated and compared according to the several criteria and then analyzed in term of return-risk relation, their availability and according to their initial costs.

2 Company characteristics

Goal of this thesis is to describe, analyze, verify and apply chosen hedging strategies which can be used for financial hedging in BorsodChem company. There will be basic characteristics of company history, environment and financial situation in this chapter.

2.1 History of the company

The history of chemical plant in Ostrava-Mariánské Hory is bounded with the beginnings of the production of nitrogen fertilisers in Czechoslovakia and closely related to the production of coke and subsequent processing of coke oven gas.

Plant building in Ostrava – Czechoslovak nitrogen Substances Work – began in 1927 and already in 1928 were produced first tonnes of ammonia and ammonium sulphate.

Production program of the plant was expanded step-by-step, first of all with inorganic products, such as nitric acid, other types of fertilisers and technical gases.

Since the fifties the share of organic products has been growing. Today organic products constitute dominant product range in MCHZ.

In 1985 started operate and produce the most important investment of the company – the aniline block. It consists of technologically linked-up hydrogen, concentrated nitric acid, nitrobenzene and aniline production units. The expansion of the cyclohexylamine and dicyclohexylamine production in the early nineties and later special amines production has brought the company's amine portfolio another step forward.

During the time of existence the company has undergone several organizational changes, including its name. Title of the Borsodchem Company changed six times since the beginning. The original name was Československá továrna na dusíkaté plyny and it was changed into state-owned company Ostravské chemické závody, then another state-owned company Dusíkárny and for the fourth time into state-owned company Moravské chemické závody in 1958. Important change happened in 1990 when the company was transformed from state-owned company into state-owned joint-stock company.

The privatisation of the company was started in 1992. The Chemapol Group, a. s. has been the majority shareholder of the Company since the 1996. In 1998 were chemical companies of Chemapol group merged into Aliachem. Then in 2000, finally, the Hungarian company BorsodChem bought a considerable part of the Aliachem division, Moravské chemické závody. Name was changed into BorsodChem MCHZ, s.r.o. BorsodChem Zrt. Hungary is 100% owner of this factory. Organisational structure is figured in the Supplement 1.

2.2 Basic facts about company

Company name:	BorsodChem MCHZ, s.r.o.
Legal entity form:	Limited Liability Company
Place of company:	Chemická 1/2039, Ostrava-Mar.Hory, PSČ 70903
Registration number:	26019388
Date of beginning:	15.12.1999
Business activities:	production and selling of organics and inorganic chemicals and technical gases
Authorized capital:	CZK 865 100 000,-

2.3 Commercial policy and supplier-costumer relations

Commercial policy of company is based on analyzing of market opportunities, competition and the market segments the company is interested in. Essentially, it is based on direct personal contacts with final users, even in cases when services of intermediary company are used to carry out the transaction. This provides an early identification of customer's needs and any changes, thus establishing basic prerequisites for a fast and professional response to changes in the market situation, including the regular review and update of the Company's investment policy.

Commercial activities are divided into two product groups – basic chemicals – aniline, cyclohexylamine, dicyclohexylamine, diethyl oxalate and second group are special amines (benzylamine, Cyclopentylamine, etc.).

The products of BorsodChem MCHZ, s.r.o., are used in various industrial sectors, mainly in the polyurethane industry, rubber chemicals industry, dyes industry, and pharmaceutical and food industry.

Most of the relevant markets has good competition environment for the company. Some of them are competition free and BorsodChem Company has dominant position. Suppliers and customers are always very different due to more purchased chemicals which are changing its appearance in the production process. In the following Tab 2.1 is an overview of three basic chemicals, supplying companies and currencies they are purchased in.

Tab 2.1: Main suppliers of BorsodChem

Chemical	Company	Currency
Benzene	Petrochemia Blachownia (Poland)	EUR
	Mol Group (Hungary)	EUR
	Deza (CZ)	CZK
Natural gas	Vemex	USD
Ammonia	BorsodChem (Hungary)	EUR
	Unipetrol	EUR
	UralChem	USD

Chemicals mentioned in Tab 2.1 are the most importing for the production process. Due to these chemicals may another such as aniline, dicyclohexylamine, nitric acid, etc. be produced. Company customers together with currencies the payment is in are in the following Tab 2.2.

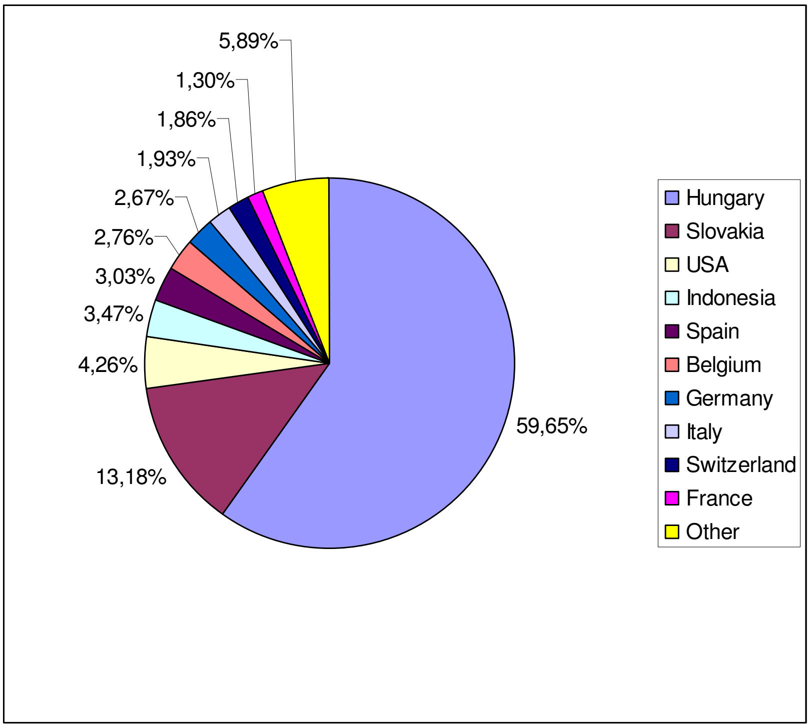
Tab 2.2: Main customers of BorsodChem

Chemical	Company	Currency
Aniline	BorsodChem (Hungary)	EUR
	Duslo (Slovakia)	EUR
	Draslovka (CZ)	EUR
Nitric acid	Only BorsodChem (Hungary)	EUR
Cyclohexylamine	San Fu Chemical (Taiwan)	USD
	Brenntag (Germany)	EUR
	GE Betz (USA)	USD
Dicyclohexylamine	Nalco (USA)	USD
	GE Betz (USA)	USD

BorsodChem Company doesn't have any significant competitors in the Czech Republic. Company is primarily supplier because they are in monopoly position in production of aniline and cyclohexylamine. But we can find some competitors in Europe. Aniline production is limited by 165.000 tonnes capacity and in Germany, Bayer Company has double capacity (around 300.000 tonnes), another competitor is company Hantzmen. This company is producer of cyclohexylamine as well.

Most, around 97%, of the sales revenues is realized on foreign markets, particularly in Central and Western Europe. The key European countries are Hungary, Slovakia, Italy, Germany and Belgium. The primary overseas country is Indonesia. Export sales divided by countries are figured in Figure 2.1. For example key product – aniline – sales inland were 53 846 thousand CZK in comparison with 2 831 372 thousand CZK sold outland in 2008. Company is using three currencies CZK, EUR and USD. Most of the transactions are done in EUR currency even some payments done in the Czech Republic. USD is used for some necessary payments such as for example transportation. Because of constant evaluation and devaluation of CZK especially during last years, company is facing significant currency risk. They are trying to prevent losses by using financial derivatives.

Figure 2.1: Export sales by country in 2008



There is summary of sales of product and services in the following Tab 2.3. As we can see, sales were constantly growing till the year 2008. This year was crucial for almost all companies all over the world. Impact of economic recession due to economic crisis was seen on all financial markets. Loss of BorsodChem Company was result of these changes as well as subsequent changes in business sector. There were several organizational changes inside company too because of efforts to streamline management structures. In 2009 we can see significant decrease of sales caused by continuing uncertainty of CZK currency and mainly by rapid change in Benzene prices.

Tab 2.3: Sales of product and services (thousands CZK)

Year	2003	2004	2005	2006	2007	2008	2009
Sales	2 951 463	3 920 407	4 400 241	5 116 806	5 268 180	4 227 062	2 722 645

The principal reasons that impacted financial results of company were as follows: the decrease in sales of key product – aniline; the rapid increase in prices of ammonia, natural gas and electricity and specifically the sudden decrease in prices of chemical products in last month of 2008. Another important factor was significant strengthening of Czech crown exchange rate with respect to EUR and USD. Companies sales are mostly in foreign currencies and this situation had of course negative impact on financial results. Not to have only negative information, there was increase in sales of cyclohexylamine and dicyclohexylamine. Profit and loss results can be seen in Tab 2.4.

Tab 2.4: Profit or loss figure (thousands CZK)

Year	2003	2004	2005	2006	2007	2008	2009
Profit or loss	253 543	118 850	185 090	38 311	65 730	-204 277	31 704

2.4 Financial plan for 2010

As was mentioned above, Company is trading mainly in foreign currencies and that is the reason why is company facing significant currency risk. In spite of trading with foreign countries there is lot of payments that has to be made in Czech crown, for example trading with some Czech companies, energy payments, wages etc. This risk can be decreased by using financial derivatives.

Company's management is forecasting fixed financial plan for whole year in advance. Then the plan and reality are compared by EBIT indicator. They agreed on having fix CZK/EUR rate 26,465 for whole year. It is better for company and their accounting department because there is certainty in calculations. On the other hand in case of high unexpected fluctuation it can be dangerous as well. During the year 2008 company wanted to have the same strategy with fixed exchange rate 25,50 CZK per EUR but during the first half of the year they changed it into daily rate and it was not good in final result at the end of the year. Even though the Czech crown had strong fluctuations it was better to keep, at the first sight, unprofitable fixed rate than change it. So the company is keeping this strategy for 2010.

2.4.1 Strategy of currency risk management

BorsodChem Company is using financial derivatives to eliminate potential losses which can originate from their foreign business operations. BorsodChem Zrt. published directive to currency and interest hedging operations. Company has to use zero cost hedging strategies in every moment.

Nowadays BorsodChem makes contracts only with Raiffeisen Bank but during last year there was contracts made with Royal Bank of Scotland and UniCredit Bank as well.

Company has monthly surplus of 5 million EUR and shortage of 1 million USD. US dollars are necessary for gas and transport payments which are executed only in dollars.

There are two ways how the contract can be begun: either financial manager contacts bank or bank contacts financial manager with some suitable offer. Financial manager is responsible for choosing the most suitable zero cost hedging strategy. It can be spot or some of several types of term operations such as forward, swap or option.

There are not satisfied criteria for accounting derivatives as hedging derivatives so in company's accounting books we can see derivatives as business derivatives in balance sheet account nr.373 and 414. Details are held in off balance sheet under nr.761 and 762 – Receivables and Liabilities to fix term operations.

2.4.2 Strategy of commodity risk management

BorsodChem is chemical company. Without any deeper research we can say that this company faces commodity risk. They import base chemicals and export products for other process. Commodity market is very volatile. For example among base and precious metals spot volatility ranges from 12 to 25 percent per annum on the other hand energy products range from 30 to 96 percent per annum, see Jorion [12]. As was mentioned above company had significant decrease of sales in 2009 just because of high volatility.

Company is not using derivatives for hedging. They use special price formulas.

Price of aniline is counted as follows

$$Aniline = 0{,}86 \cdot Benzene\ \mathrm{Pr}\,ice + \phi, \tag{2.1}$$

where *0,86* is fixed value, *Benzene Price* is monthly price predicted by ICIS and ϕ is sum of some variable cost such are transportation, energy and then appropriate profit or value reducing loss.

As for gas, there is following formula

$$Gas = Petroleum\ price + Carbon\ price + Light\ fuel\ oils\ price, \tag{2.2}$$

where *Petroleum price* is price with 8 month delay and *Carbon* and *Light fuel oils price* is price valid in the moment of pricing. Due to this formula, company management is able to predict revenue evolution for eight month at least approximately.

The commodities are evaluated according the ICIS pricing. ICIS is part of Reed Business Information Ltd.[1] providing daily and weekly reports. BorsodChem is one of their customers and has weekly reports for pricing their products. Example of complex Benzene price report from 5th February 2010 is in the Supplement 2.

2.4.3 Interest rate risk

Company has credit from BorsodChem Zrt. in EUR. It is not hedged but because it is at the level of whole group it is not as necessary as in a case of bank credit etc. Company had interest rate swap and forward rate agreement as well in the past but it was not good experience for them.

There is no significant need to solve problem of commodity or interest rate risk in BorsodChem company and that is why we will be trying to solve problem of currency risk in this thesis.

[1] It is Europe's biggest online and offline publisher.

3 Hedging instruments and strategies description

This theoretical chapter was written mainly on foundation basis of these authors – Hull [8], Jílek [10], Tichý [13] and Zmeškal [14].

One of the most important assumptions for successful business is to handle risks. Risk hides uncertainty from future and it can be with positive or negative result in the end. First subchapter describes risk. According to this recognition we have to at least try to forecast this future uncertainty to prepare on potential negative impacts and try to avoid them. Subchapters 3.2 – 3.6 are dealing with this topic.

3.1 Financial risk

Whole business activity is related with risks. Main goal of every business subject is to gain profit. However every subject has to count with potential financial loss, in other words financial risk, as well.

Risk can be in finance generally characterized as the probability that current results will be different than expected results. Risk is differentiated into systematic and unsystematic. Systematic risk is risk inherent in the aggregate market evoked by common factors and influences in different measure affecting all subjects on the market. Sources of systematic risk are for example changes in monetary or fiscal politics, tax changes, recessions, wars, interest rates and others. This risk cannot be fixed with diversification because of its common character.

On the other hand unsystematic risk (also known as specific risk) is specific for individual companies or their investments. Company or industry specific risk is inherent in each investment. The amount of unsystematic risk can be reduced through appropriate diversification. Sources of this risk can be for example failure of main sub supplier, entering of new competition to the market, damage of production facility, leaving of key firm employees etc.

Financial risk can be divided into five groups: credit, market, liquidity, operational and business risk. It is obvious that all of them can cause gain or loss in companies and it has influence in different amounts, individually or in combination. Loss can be expected or unexpected.

In the Figure 3.1 we can see on of the possible decomposition of financial risks.

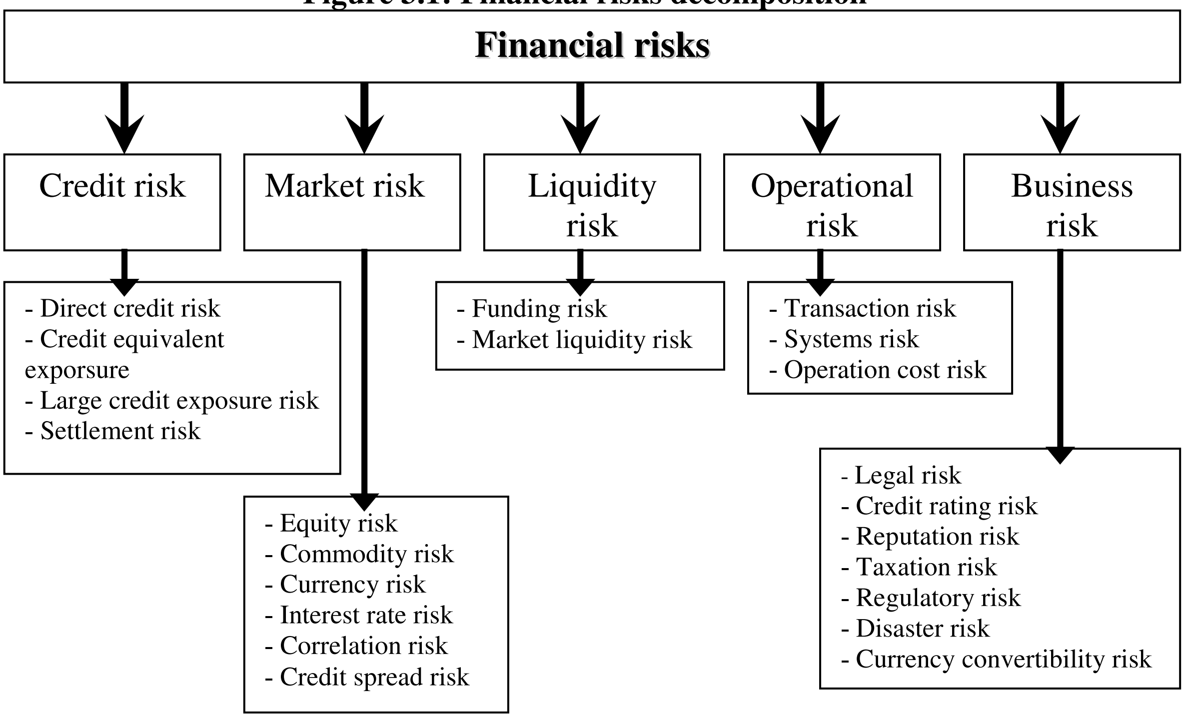
Credit risk

Credit risk is possibility of potential loss from the failure of counterparty to fulfil its contractual obligations either from insolvency reason or from payment unwillingness. Credit risk can be minimized by receivables management, which includes monitoring of customer payment attitude.

Market risk

Market risk is after credit risk second most significant risk from risks mentioned above. It can be defined as potential unexpected loss that can be caused by movements in the level or volatility of market prices, which means change in financial instrument prices of single asset types such as equities, interest rate, bond price, currency rates, commodity prices and financial derivatives prices. There are four basic groups of market risk: interest rate risk, equity risk, commodity risk and currency risk. In some publications there is mentioned correlation and credit spread risk as well.

Figure 3.1: Financial risks decomposition



Source: Jílek, J.; *Finanční rizika*, 2000; p. 16-17

Interest rate risk can be defined as potential loss which originates in unfavourable interest rate progress. It the major risk for bondholders.

Equity risk means potential loss from price changes of instruments sensitive to equity prices or movements in the value of equity prices.

Commodity risk means potential loss which arises from movements in the value of commodity contracts, which include metals, energy products or agriculture products.

Because this thesis is dealing mainly with currency risk, there will be special part about currency risk.

Liquidity risk

Liquidity is firm ability to settle its payable liabilities in every moment. So liquidity risk presents possibility that business subject is not able to settle the liabilities because of lack of liquidity assets.

Operational risk

Generally operational risk means possibility of loss because of operational imperfection and faults. In close conception we can think about operational risk as about risk resulting from firm operations. In wide conception there are all the risks which cannot fall under the category of risks mentioned above. This risk is hard to quantify.

Business risk

Business risk is risk connected with business activity and it has influence on firm revenue value and eventually to the total firm value.

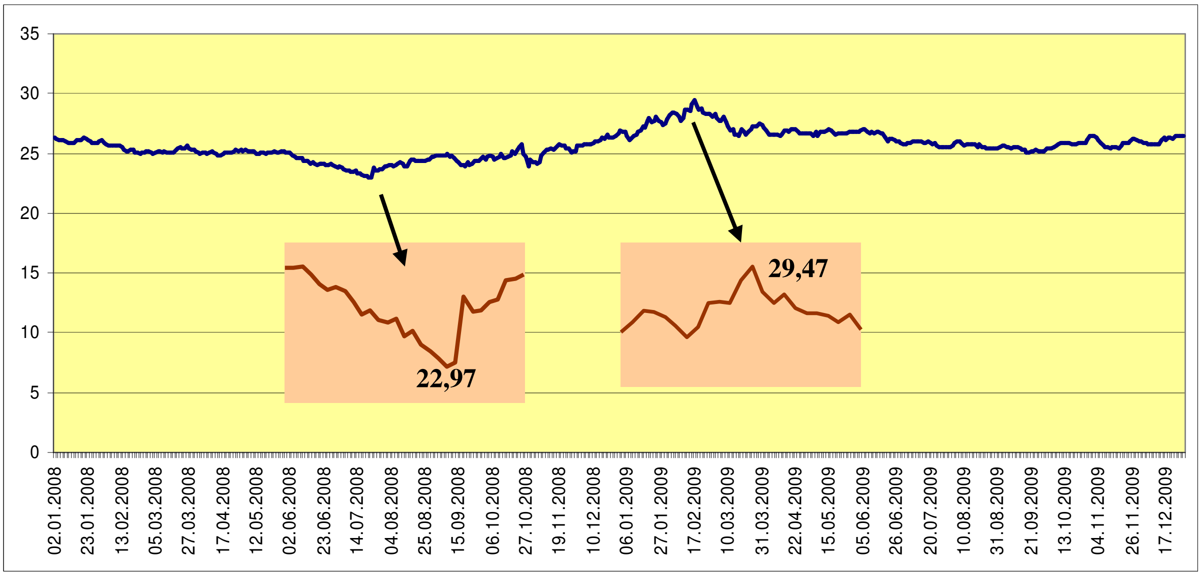
3.1.1 Currency risk

One of the market risk types is currency risk. Currency risk, often called as exchange rate risk as well, is form of risk which is caused by changes in exchange rate of one currency against another. Whenever investors or companies have assets or business operations across national borders and their assets and liabilities in foreign currencies are not balanced, they face currency risk.

It flows mainly from business participation in foreign trade, physical or capital investments realisation abroad or gaining of credit financing in foreign currencies. Financial markets are typical for their high variability, especially during last year, and it can cause unfavourable development of financial results or competitiveness of companies.

In case of importer when outcome exceed amount of income in this currency and Czech crown equivalent of this outcomes increase with weakening of Czech crown currency rate against another currency. In case of exporter on the other hand incomes in foreign currency exceed amount of outcomes in that currency and crown equivalent of that incomes decrease with strengthening of Czech crown against foreign currency. Second situation is real problem for companies in the Czech Republic. If they do not hedge their incomes in foreign currency effectively they are loosing expected profit as it happened in 2008 and 2009 during financial crises when Czech crown was very volatile as we can see in Figure 3.2.

Figure 3.2: CZK/EUR development during 2008 and 2009



Goal of every company should be to undergo an adequate risk level. We cannot eliminate all types of risk but most of them can be significantly decreased by good managing and using of suitable hedging instruments.

3.2 Volatility estimation

Important part of financial modelling is volatility estimation because volatility is basic parameter for financial risks management. Volatility expresses volume of uncertainty of future variable values. Volatility has to be considered when we predict currency development, evaluate options, hedge or for example optimize portfolio.

There is several ways how to estimate volatility. We can obtain volatility value from set of historical data series but because of homoscedasticity presumption which is not often fulfilled we usually apply special models which work with conditional volatility such as for example ARCH, GARCH and EWMA model.

Generalized autoregressive conditional heteroscedasticity[2] model developed by Engle and Bollerslev assumes that the conditional variance depends on the latest innovation but also on the previous conditional variance.

GARCH (1; 1) for one period forecast is defined as follows

$$Y_{t+1} = \hat{y}_{t+1} + \varepsilon_{t+1}, \tag{3.1}$$

$$\sigma^2_{t+1,t} = \omega + \alpha \cdot \varepsilon^2_t + \beta \cdot \sigma^2_{t,t-1}. \tag{3.2}$$

Variables α, β, ω are estimated parameters. Two conditions has to be fulfilled - $\alpha, \beta, \omega \geq 0$ and $\alpha + \beta < 1$. y_{t+1} is real value of predicted financial variables, $\hat{y}_{t+1}$ is its estimation in time t, ε^2 is real variance in time t, $\sigma^2_{t+1,t}$ is estimated variance in time t for time $t+1$ and $\sigma^2_{t-1,t}$ is estimated variance in time $t-1$ for time t.

(1;1) behind GARCH means that predicted variance is based on the last ε observation and on the last variance rate σ^2 estimation.

EWMA model is particular case of the GARCH (1; 1) model which works only with one parameter, where $\omega = 0$, $\alpha = 1 - \lambda$, $\beta = \lambda$ and $0 \leq \lambda \langle 1$,

$$\sigma^2_{t+1,t} = (1-\lambda) \cdot \varepsilon^2_t + \lambda \cdot \sigma^2_{t,t-1}. \tag{3.3}$$

EWMA model is used for forecast of volatility and correlation in J.P.Morgan and Reuter's RiskMetrics.[3] The exponential weighting is done by using a decay factor λ. It takes value from 0 to 1. The larger the value of λ the more weight is placed on past observations and so the smoother the series becomes.

We can estimate the value of model parameter which it called decay factor λ by RMSE criteria minimization

$$RMSE = \sqrt{\frac{1}{T} \cdot \sum_t z_t}\ , \tag{3.4}$$

where $z_t = \varepsilon^2_t - \sigma^2_{t,t-1}$ and z_t means prediction fault.

Advantage of EWMA model is that it is not necessary to keep line of historical data, and it is easier to estimate and predict volatility.

[2] Heteroscedasticity means changing variance.

[3] Alexander, C, Risk Management and Analysis, p.130

When we are predicting volatility it is necessary to count from continuous log returns R_t, according to (3.5) formula

$$R_t = \ln \frac{P_t}{P_{t-1}}, \tag{3.5}$$

where P_t means price of underlying asset, in our case currency rate, in time t,

P_{t-1} characterize price of underlying asset in time $t-1$.

One-day log return R_t is going to be used for currency rate forecast through Brown geometric process with log prices.

3.2.1 Monte Carlo simulation

Simulations involve creating artificial random variables with properties similar to those of the observed risk factors. Among these risk factors may be exchange rates, bond yield or prices, stock prices or commodity prices.

Principle of Monte Carlo simulation is to generate big number of scenarios, hundreds or thousands and calculation of financial criteria values for every scenario.

More number of trial simulations we do bigger chance to have probability distribution simulation similar to the real one.

Base of majority of the processes which describe stochastic development of financial asset prices is risk element. It can be simulated through continuous process (Wiener Process) or jump changing process (Poisson Process).

The Wiener Process, sometimes called The Specific Wiener process, is continuous process and it is basic element of other processes.

It has two presumptions. The increments Δz are across time independent and predicted prices are influenced only by current price, historical price is irrelevant. It follows stochastic Markov process where the whole distribution depends on the current price only.

The Wiener process is given by

$$\tilde{z}_t - z_0 \equiv dz = \tilde{z} \cdot \sqrt{dt}\ , \tag{3.6}$$

where z is random variable from normal distribution $N(0;1)$.

Mean value of this process is $E(dz) = 0$, variance $\operatorname{var}(dz) = t$ and standard deviation $\sigma(dz) = \sqrt{t}.$

If we consider price movement in time for several time intervals then

$$\tilde{z}_T - z_0 = \sum_{i=1}^{n} \tilde{z}_i \cdot \sqrt{dt}\ , \tag{3.7}$$

meaning of values remains same but $E(\tilde{z}_T) = 0$, $\text{var}(\tilde{z}_T) = n \cdot dt = T$, $\sigma(\tilde{z}_t) = \sqrt{T}.$

Arithmetic Brownian motion, often called as generalized Wiener Process, is defined as follows

$$dx = \alpha \cdot dt + \sigma \cdot dz \tag{3.8}$$

First part of this formula, $\alpha \cdot dt$, defines trend where in time length equal dt there is increment in value equal $\alpha \cdot dt$. Second part, $\sigma \cdot dz$, is residual and it is composed from specific Wiener Process dz and σ of increment in value in certain time. Price has a linear trend $E(dx) = \alpha \cdot dt$, $E(x_T) = x_0 + \alpha \cdot T$, $\text{var}(dx) = \sigma^2 \cdot dt$, $\text{var}(x_T) = \sigma^2 \cdot T$.

It is used rarely in finance but it is often used in physics for physical variables.

There is Geometric Brownian motion used for finance modelling. It is widely used for stock prices and currencies. Process is exponential, not linear as it was in arithmetic process and probability function is unsymmetrical, it means log normal. The lognormal distribution prevents prices from turning negative, it is more realistic. It does not matter if the horizon is for example one day because there cannot be such a big change in one day but in the horizon of two years there can be expected big changes.

Geometric Brownian motion formula is given by

$$dx = x \cdot \alpha \cdot dt + x \cdot \sigma \cdot dz\ , \tag{3.9}$$

where $\dfrac{dx}{x} = \alpha \cdot dt + \sigma \cdot dz$

and mean value with the variance can be expressed similarly as before,

$$E(dx) = \alpha \cdot dt,\ E(x_T) = x_0 + x_0 \cdot \alpha \cdot T,\ \text{var}(dx) = \sigma^2 \cdot dt,\ \text{var}(x_T) = x_0 + x_0 \cdot \sigma^2 \cdot T.$$

The Geometric Brownian Motion is particular example of Itô process. It is widely used for stock prices and currencies.

Itô Lema process is general type of stochastic process. Itô formula enables to express increment of process df in case that its inside function cannot be differentiated. It is defined for variable x as follows

$$dx = a(x;t) \cdot dt + b(x;t) \cdot dz, \tag{3.10}$$

where $a(\cdot)$ is increment and $b(\cdot)$ standard deviation of variable change.

Important modification of Brownian motion is Geometric Brownian motion with logarithmic prices which is used for financial modelling, e.g. for options evaluation. If the variable is developing according to process described in (3.9) and Itô's Lemma is used for function $G = \ln x$, it is possible to prove that

$$dG = d \ln S = \alpha \cdot dt + \sigma \cdot dz \,. \tag{3.11}$$

When we use Geometric Brownian Motion with logarithmic prices, random price development of financial asset is given by

$$x_t = x \cdot \exp(\alpha \cdot dt + \sigma \cdot dz) \tag{3.12}$$

where $\alpha = \mu - \frac{\sigma^2}{2}$, $\mu = \ln \frac{S_T}{S}$.

3.2.3 Returns correlation

If we want simulate portfolio of assets it is necessary to take into consideration correlations between assets and count with this fact. In this thesis we simulate evolution of two assets – currencies CZK/EUR and CZK/USD. Correlation dependence of these two assets is given by correlation coefficient ρ

$$\rho = \frac{\operatorname{cov}(x, y)}{\sigma(x) \cdot \sigma(y)} \,, \tag{3.13}$$

where $\sigma(x)$ is standard deviation of asset x and $\sigma(y)$ is standard deviation of asset y, $\operatorname{cov}(x, y)$ is covariance which gives us information about connection between these two assets. Covariance formula is following

$$\operatorname{cov}(x, y) = E\left[(x - E(x)) \cdot (y - E(y))\right]. \tag{3.14}$$

Value of correlation coefficient is moving within the range $[-1; 1]$. $\rho = 1$ means that returns are absolutely positively correlated and it means that assets are dependent and act the same way. On the other hand result $\rho = -1$ shows that returns are the most negatively correlated and assets are acting conversely. Returns are independent if the value of coefficient is 0.

Correlation is necessary when we generate random variables. One of the possibilities is to do generation of random vector according to Cholesky algorithm also called Cholesky triangle as follows

$$\vec{z}^{\,T} = \vec{e}^{\,T} \cdot P \,, \tag{3.15}$$

where $\vec{\varepsilon}$ is vector of random variables from normal distribution $\phi(0;1)$ and P is upper triangle matrix derived from the covariance matrix.

As was mentioned above we think about simulation of two assets, particular elements of the matrix $p = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix}$ are counted as follows

$$p_{11} = \sqrt{\sigma_{11}} = \sigma_1 \ , \tag{3.16}$$

$$p_{12} = p_{21} = \frac{\sigma_{12}}{p_{11}} = \frac{\sigma_{12}}{\sigma_1} \ , \tag{3.17}$$

$$p_{22} = \sqrt{\sigma_{22} - p_{12}^2} = \sqrt{\sigma_{22} - \frac{\sigma_{12}^2}{\sigma_1^2}} \ , \tag{3.18}$$

where σ_{11} is variability of the first asset, σ_{22} is variability of the second asset and σ_{12} is correlation between these two assets counted as mentioned before according to (3.13).

Now it is necessary to modify generated random variables. After adjusting of formula (3.15) we obtain

$$z_1 = \varepsilon_1 \cdot p_{11} + \varepsilon_2 \cdot p_{21} \ , \tag{3.19}$$

$$z_2 = \varepsilon_1 \cdot p_{12} + \varepsilon_2 \cdot p_{22} \ , \tag{3.20}$$

where z_1 and z_2 are dependent random variables.

3.3 Exchange position

Foreign exchange position is relation between exchange assets and liabilities of certain currencies from quantity, maturity and interest running point of view.

It is not a rule that every company has to undergo exchange risk every time. If company has balanced assets and liabilities in foreign currency then the company is in closed foreign exchange position and there is no exchange risk.

Open foreign exchange position is distinguished by positive or negative value of assets and liabilities in certain currency for certain time period. In this case company is exposed to exchange rate risk. We differentiate between two types, long and short open foreign exchange position. When exchange assets exceed exchange liabilities then we are in long position. Whereas when exchange liabilities exceed exchange assets we are in short position.

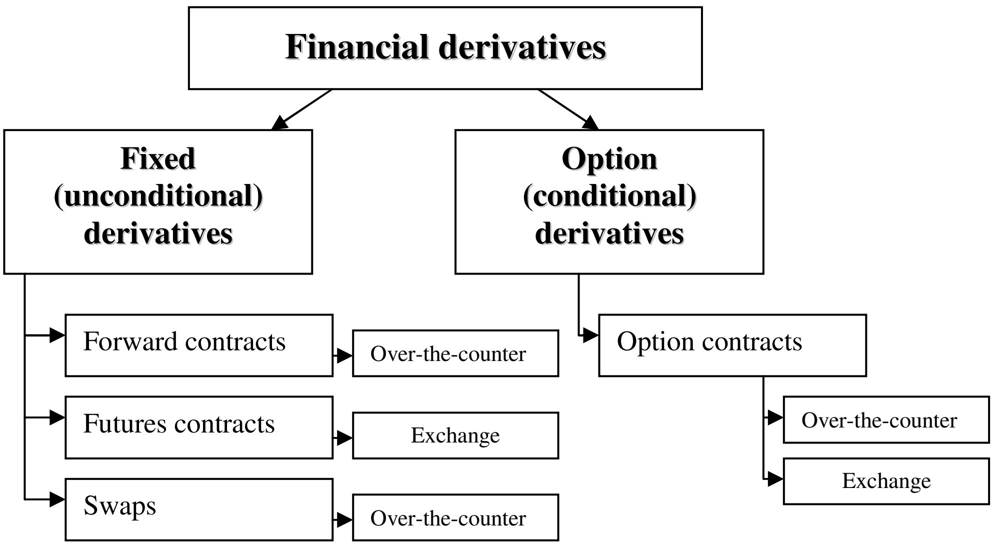
3.4 Derivatives

Financial derivative is financial instrument whose value is derived from value of another financial instrument called underlying asset. Pay off function is dependent on one or more underlying assets or factors. It happens very often that the underlying derivative variable is price of traded asset and from this point of view we can differentiate between equity, commodity, currency and interest rate derivatives. Nevertheless these are only basic types, there are plenty of existing derivatives and underlying assets as well and there are still appearing new ones. Derivatives can be dependent on hours of sunshine, quantity of snow, rainy days within a year etc.

Because BorsodChem Company has relatively hedged their commodity risk and their interest rate risk this thesis will be concerned mainly about currency risk, it means the underlying asset is exchange rate.

When we talk about financial derivatives in exchange markets we can classify them according to maturity time into spot and term (forward) operations. If the settlement of financial asset contract is done in the same time as it is arranged we talk about spot operation in the spot market. This settlement is usually done within two days, $t+2$, with spot rate. On the other hand if the settlement is arranged for certain time in future, $T = t + \tau$, we specify this contract as term (forward). Forwards, futures, swaps and options are example of term operations.

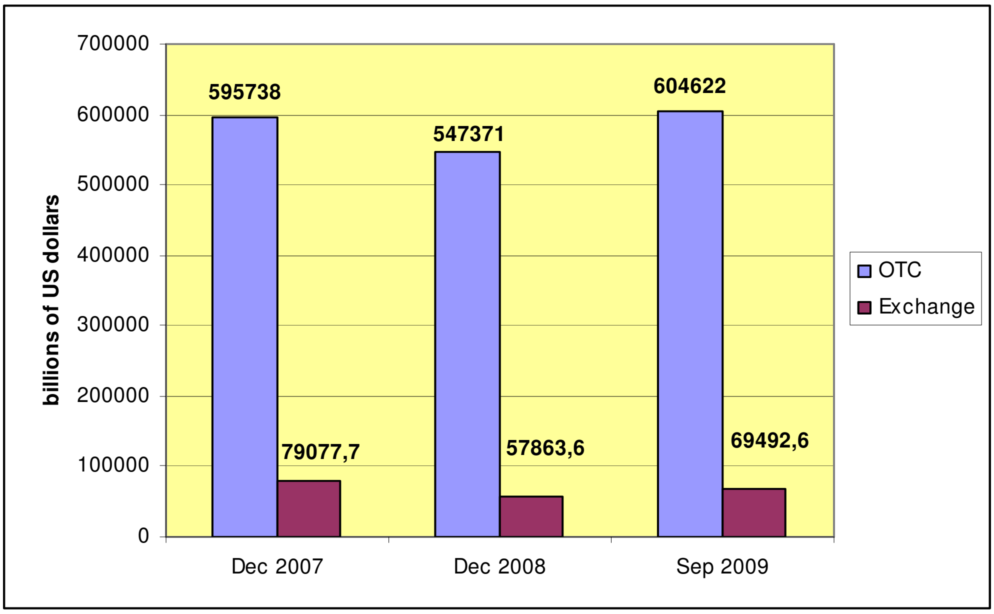
Figure 3.3: Financial derivatives



Derivatives can be traded either on exchange or over-the-counter. Exchange derivatives are traded as standardized contracts defined by exchange. Every exchange has precisely stated contract parameters, for example strike price, volume, maturity time, type of product, measuring unit etc. OTC is an alternative to exchange but contracts are traded directly between two parties and trades are unregulated so it depends on both sides what conditions can be contract settled for. In the following Figure 3.4 we can see that OTC contracts are traded much more than exchange-traded contracts.

The most common exchange-traded derivative instruments are interest rate futures and options. In North America has the biggest volume of interest rate futures and Europe has the biggest volume of interest rate options.[4]

Figure 3.4: Volumes of exchange-traded and OTC contracts
(Notional amounts in billions of US dollars)

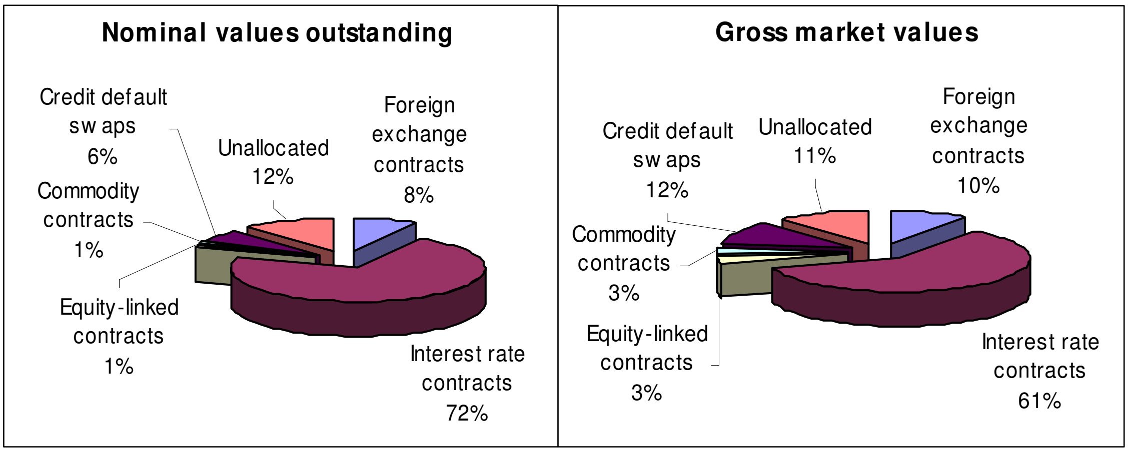


Source: International Banking and Financial Market Developments, BIS, Basel 2009

Following Figure 3.5 shows the structure of OTC derivatives from a risk point of view. There are mentioned just derivatives for market risks in the figures which are for this thesis the most important. As we can see interest rate contracts are again the most traded ones. And just for better imagination 72% is equivalent to USD 437 198 billion and foreign exchange contracts value is USD 48 775 billion.

[4] According to International Banking and Financial Market Developments, BIS Quarterly Review, Basel 2009

Figure 3.5: Structure of OTC derivatives by risk category



Source: International Banking and Financial Market Developments, BIS, Basel 2009

According to the right and obligation which flows from settled derivative contract to both sides we differentiate between two types of contract:

- fixed (linear, unconditional) contract where both sides are oblige to realize in certain time in future contract settled in present time;

- option (conditional) contract where only one of the partners (sides) has obligation to realize the contract if the second partner wish it. Second partner has the right to realize that deal or not.

Forwards, futures and swaps belong to unconditional contracts and on the other hand different types of options (exotic, barrier, cap, floor, collar, etc.) are classified as conditional contracts.

3.4.1 Reasons for derivatives application

Foreign exchange operations are settled for three basic reasons. It can be speculation, arbitrage or hedging. Other derivatives operations such as dealing with interest rates, equities, commodities etc., have the same reasons and purpose but for this thesis we will approach foreign exchange operations.

Speculation in general is taking risk in revenue expectation from positive progress of future prices. It is type of exchange operation settled only for revenue. Speculator has some idea about future progress and he is opening exchange rate position. Unfavourable price progress means for speculator loss. His position is open. In general we can say that more and better information certain speculator has more successful he is.

Arbitragers are trying to take advantage from different currency prices on different markets. Their goal is to gain profit from small differences between price of currency on one market and the same currency with higher price on the other market. Difference between arbitrager and speculator is that profit of arbitrager is not bounded with risk. Problem is that markets are nowadays highly interconnected so possibilities for arbitrage are relatively small.

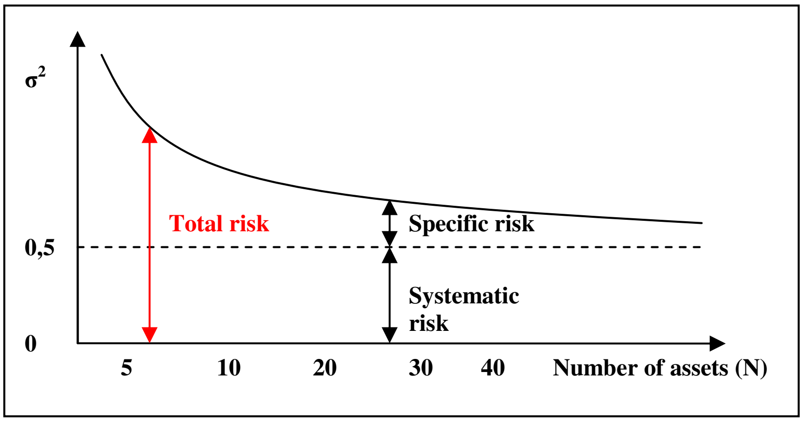
Hedging as the only one is not settled for profit gaining. In general it is protection of value of certain asset or asset portfolio against unfavourable progress in prices. Hedgers are trying to hedge their open position against exchange rate risk through hedging operations. It can be understand as closing of own positions.

3.4.2 Hedging

If it is possible to measure risk then it is possible to manage it too. There are two methods how risk can be managed, either by diversification or hedging.

Risk is divided into systematic which can be eliminated by appropriate hedging strategy and specific. Specific risk is decreasing with increasing assets volume. Figure 3.6 shows both risks.

Figure 3.6: Specific and systematic risk



Hedging in general means process of systematic financial risk elimination. The task of hedging can be characterized on a simple example. Let's imagine that we own one risky asset or portfolio of risky assets and we will connect it with new group of assets and by that new hedging portfolio will be created and it will be hedged against risk of changes of assets in portfolio which means that its returns will be against these changes utmost immune and predictable.

Hedging methods can be characterised and distinguished according to a wide range of criteria.[5] The most important ones are:

- the number of revisions in time
    - static (passive) for one period,
    - dynamic (active) for more periods;
- the frequency of revisions:
    - in discrete-time,
    - in continuous-time;
- the type of the risk, which is hedged:
    - whole risk,
    - systematic risk;
- the hedging objectives:
    - factor-neutral, such as delta hedging, delta-gamma hedging, immunization on the basis of duration etc.,
    - the variance minimization,
    - minimization of the shortfall mean,
    - minimal Value at Risk,
    - maximization of the expected utility function,
    - minimization of the risk adjusted return on capital;
- the type of the asset we hedge:
    - stocks,
    - bonds,
    - currencies,
    - futures,
    - options,
    - commodities;
- whether the hedging is performed with respect to some etalon or not:
    - benchmark hedging,
    - hedging without etalon.

Currency delta hedging

Option pricing is about finding f. Option hedging uses the partial derivatives. Main idea of delta hedging strategy goes from the fact that the increment in the value of hedged

[5] Zmeškal, Z.: Financial models, p.152

portfolio is generally expressed by linear function, usually with approximation on the basis of the Taylor series expansion. Then we look for such an optimal portfolio composition where increment in the value of hedged portfolio is zero.

Delta belongs with others into so called Greeks parameters and it is the most important sensitivity indicator, it is first partial derivative with respect to price.

Delta is mathematically defined as

$$\delta = \frac{\partial V}{\partial S}, \tag{3.21}$$

where V is the value of portfolio or the price of derivative and S is price of underlying asset.

It expresses how price of derivative or portfolio value would be changed as result of one unit change in the price of underlying asset. We assume all other variables are not changed. For call option delta must be between zero and one and for put option delta must be between zero and minus one. More is the option out of money more is the value of delta lower and vice versa. For at-the-money option is delta value approximately 0,5. It can be interpret as well as hedge-ratio or probability that option will be exercised in maturity time.

Increment of the value of function $\Delta F(x)$ is in generally defined as follows

$$\Delta F(x) = \frac{\partial F(x)}{\partial x} \cdot \Delta x + \frac{1}{2} \cdot \frac{\partial^2 F(x)}{\partial x^2} \cdot \Delta x^2 + \frac{1}{6} \cdot \frac{\partial^3 F(x)}{\partial x^3} \cdot \Delta x^3 + \mathrm{K} \tag{3.22}$$

In case of currency delta hedging risk factor is exchange rate. Value of hedged portfolio is given with regard to current market value of hedged exchange rate by

$$\Pi_t = Q \cdot e^{-r_f \cdot (T-t)} \cdot S_t - h \cdot N \cdot f_{t,TT}(S), \tag{3.23}$$

where Q is quantity of hedged foreign currency, S_t is spot rate of currency, N is quantity of currency for one derivative, f is unit price of derivative, t is time of hedging, T is time of payment in foreign currency, TT is maturity time and it applies $t<T<TT$, h is number of forward contracts for hedging and r_f is foreign interest rate.

We presume that payments in foreign currency are stated for moment T and currency derivative, option, futures, swap etc., is hedging instrument.

The increment can be therefore expressed as follows

$$\Delta\Pi = Q \cdot e^{-r_f \cdot (T-t)} \cdot \Delta S - h \cdot N \cdot \Delta f(S). \tag{3.24}$$

Using the Taylor series approximation of the first order for increment in the value of derivative and putting into (3.24), we get

$$\Delta\Pi = Q \cdot e^{-r_f \cdot (T-t)} \cdot \Delta X - h \cdot N \cdot \frac{\partial f(X)}{\partial X} \cdot \Delta X . \tag{3.25}$$

Presumption of hedging $\Delta\Pi = 0$ must be fulfilled thus

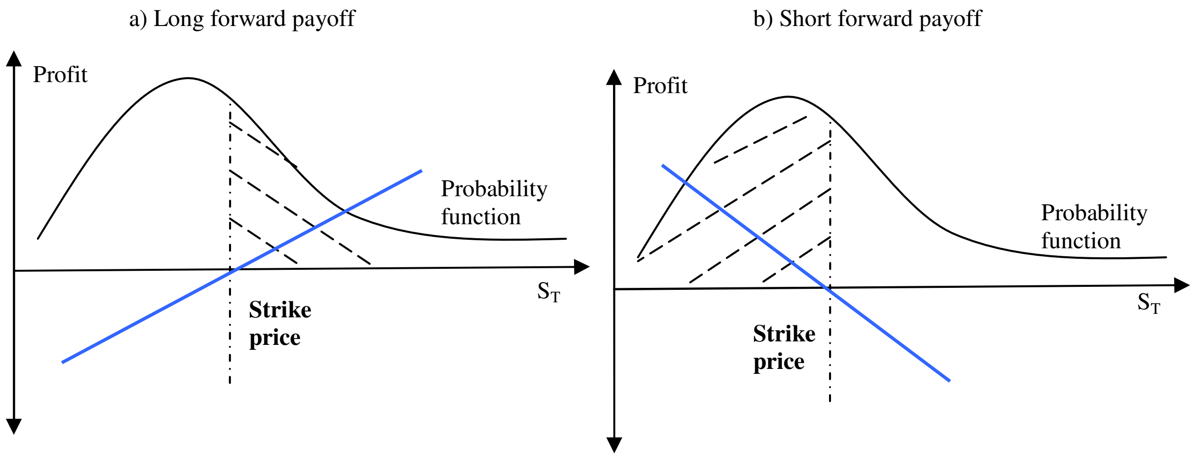
$$h = \frac{Q \cdot e^{-r_f \cdot (T-t)}}{N \cdot \frac{\partial f(X)}{\partial X}} = \frac{Q \cdot e^{-r_f \cdot (T-t)}}{N \cdot delta} . \tag{3.26}$$

3.5 Fixed contracts

3.5.1 Forward contracts

Forward contract is the oldest type of derivative contract. First forward markets were developed because of uncertainty future price trend with goal to hedge against potential unfavourable evolution. Forward contract represents obligation of buyer to buy certain asset, underlying asset, at certain time in future for agreed, strike, price. Conditions are different for each contract and that is why forward contracts are traded only outside of exchange as OTC contracts which work through telephone or computer connection between individual participants. Because the contract conditions are individual there is lower liquidity and higher risk.

Figure 3.7: Payoff of long and short forward



Core of the forward contract is that deal is made in present but maturity is at agreed time in future. Payoffs are displayed in Figure 3.7. One of the parties is in long position and agrees to buy an underlying asset which we can express the payoff as

$$g = S_t - X , \tag{3.27}$$

and the second party, which is in short position, agrees to sell underlying asset on certain future date, payoff is given by

$$g = X - S_t, \tag{3.28}$$

where X is delivery price and S_t is spot price of the underlying asset at maturity time.

It is contract for future change of underlying asset on certain specified future date. Price is settled in the moment of contract agreeing but the payment and delivery is done later.

One of the parties is usually bank or other financial institution which can act like broker or middleman. Forward is not standardized, it is financial tool with low liquidity and it cannot be cancelled without agreement of both sides.

Forward price of underlying asset can be higher, in that case it is forward with premium, or lower, then it is forward with discount, than level of spot price of underlying asset and it depends on market expectations how is the price going to develop and transmission costs.

There is no payment done at time of making agreement. Forward agreement is settled in maturity time. This brings certain level of credit risk which is one of forward negative quality.

Farer the spot price is from forward price, higher the probability of credit risk because in this situation one party has high profit but second party has high loss.

In spite of forward agreements being individual contracts where maturity time is not settled by higher power, it is typical that maturity times are 1, 2, 3, 6 or 12 month.

Forward foreign exchange contract

Forward foreign exchange contract[6] (thereinafter forex = foreign exchange) is term contract where agreement about buying or selling certain amount of foreign exchange for another foreign exchange between two parties for pre-arranged conditions is arranged. These contracts are the most widely used contracts for hedging of exchange rate risk.

Forex rate express future value of certain currency and spot rate express present currency value. Deviation between forward and spot rate usually express difference in interest rates of traded currencies. This deviation is called forward spread.

[6] Also known as outright forward or currency forward.

Advantage of forward forex contract is fact that we can hedge fixed rate according to our expectations for future conversion. Disadvantage is that in case of currency strengthening or weakening we cannot profit because of that contract.

Maturity time is usually for 1 year maximum. Longer times such as 3 or 5 years are not used because of hard exchange rate forecast for such a long time period.

Forward contract allows us to settle exercise price X. We need to know the value of forward given by

$$f_t = S_t \cdot e^{-r_f \cdot (T-t)} - X \cdot e^{-r_d \cdot (T-t)}. \tag{3.29}$$

If we assume that the value of forward f is in time of settling zero, $f_0 = 0$, than the exercise price X which is equal to forward price F_0 given by

$$X \equiv F_0 = S_t \cdot e^{(r_d - r_f)\cdot(T-t)}. \tag{3.30}$$

Non delivery forex forward

It is a type of outright forward where no real exchange is done. Open position is closed 2 days before maturity time at the latest. Profit of loss in time of maturity is difference between pre-arranged exchange rate and closing rate.

The profit is given by

$$\pi = \frac{NS - NF}{S_t} = N \cdot \left(\frac{1 - F}{S_t} \right), \tag{3.31}$$

where N is notional amount, F is agreed forward rate and S_t is current spot rate.

3.5.2 Futures contracts

Futures contract is, like forward contract, an agreement between two parties to buy or sell underlying asset at certain time in future under pre-agreed conditions. In contrast with forward contracts, they are standardized and exchange-traded.

Contract conditions are standardized and settled by rules of relevant exchange. Each trade is objectively, timely and spatially defined with minimum amount of one contract, maturity date and trading place because futures contracts are traded only at special term exchanges such as Chicago Mercantile Exchange, New York Futures Exchange, Eurex etc. Trading can be organized either classically on the floor or in the electronic form which is more and more often form of trading nowadays.

Futures contracts are traded in volumes which are called LOT and represents minimum traded quantity. Standardized amount express size of one contract. Trading can be done only with those defined contracts. Range of underlying assets is standardized as well and every exchange has directly stated instruments which can be traded as futures contracts.

Main disadvantage of forward contracts is credit risk. This risk is almost fully covered in futures contracts because they are exchange-traded and each exchange states certain level of initial and maintenance margin which has to be deposited to prevent potential risk of back out from the deal from party which is loosing.

There are two types how to settle the contract. First one is physical settlement where subject in short position delivers volume of underlying asset to the second party which is in long position and pays delivery price. Only minority contracts are settled this way because most of the contracts are usually closed prior to the maturity time by purchasing or selling covering position. It means either we buy a contract to cancel out an earlier sale if we are in short position or we sell a contract to liquidate an earlier purchase if we are in long position.

Second settlement type is cash settlement and it is usually used for financial futures where the underlying asset delivery is not possible or convenient, for example index (DJIA, S&P, Nikkei etc.). Settlement is done by daily marking to market which involves settlement of the gains and losses on the contract every day.

Every business day is found out actual contract value according to closing price. Then contract is settled in the buyers and sellers margin account. In case of gain is it added to the account and in case of loss it is taken away. Contract goes with zero beginning price to the next business day. Exercise price is changing every business day and it is equal to the last closing price. If the amount of margin account falls under maintenance margin[7], it is necessary replenish the account. This is called margin call. In case of not replenishing the account, contract is cancelled.

Forex futures

Forex futures were created in 1972 at the Chicago Mercantile Exchange (CME). CME is the largest derivatives market place[8].

Forex futures is contract to buy or sell standardized amount of one currency for another at specified date in the future for specified fixed pre-agreed exchange rate. It is typical that one of the currencies is US dollar. Future price is then in terms of US dollars per unit of other currency. Example of EUR/USD futures contract is in Supplement 3. There is not such a wide choice of currencies as in forward contract; exchanges usually trade only main world

[7] Maintenance margin level is set by the exchange. Usually it is 75% of initial margin.
[8] Average volume of 754,000 forex contracts per day was traded at the CME in the fourth quater of 2009.

currencies such as Euro, Japanese Yen, Swiss franc etc. At the CME there is possible make contract with few emerging countries currencies as well.

Forex futures are usually used for hedging of assets or liabilities in foreign currency but for speculation as well.

Most contracts have physical delivery but they are usually closed out prior to the delivery date.

At the end there are main differences between forward and futures contract summarized in Table 3.1.

Table 3.1: Comparison of forward and futures contract

Forward	Futures
Traded on Over-The-Counter Market	Traded on Exchange
Not standardized	Standardized contract
Usually one specified delivery date	Range of delivery dates
Settled at end of contract	Settled daily
Delivery or final cash settlement usually takes place	Contract is usually closed out prior to maturity

Source: Hull, C., Options, futures and other derivatives, p.36

3.5.3 Swaps

Swap is another derivatives contract type that is traded Over-The-Counter. In general swap represents an agreement in which two counterparties exchange a stream of cash flows in some repeating period of times in the future. Contract conditions define dates when the cash flows are to be paid. Most often is payment of one party fixed and payment of second party floating in dependence on chosen base or in different currencies. In some cases except the interest payment exchange principal is exchanged as well.

Main difference between all the other derivatives is that swaps settlement is not single but continuing. We can say that it represents several forward contracts with sequential exchange of underlying assets for the agreed period.

Swaps are used to manage risk, speculate and decrease transaction costs. Absolute and comparative advantage is used here, because subjects in home country have better access and interest rate conditions than foreign subjects so they can offer these conditions each other.

Currency swaps

We can define currency swaps as agreed repeating exchange of certain interest rate payments denominated in two different currencies which turns up in specified dates in future.

Real capital exchange is done between contract partners because each party needs to pay interests denominated in currency which they are disposing. Generally both partners are from different countries and with different currencies.

3.6 Option contracts

Forward contracts, futures contracts and swaps are types of fixed contracts where both sides have to fulfil agreement. On the other hand options are contracts where only one party has obligation to fulfil the contract but second party has right to decide if the contract will be fulfilled or not. This right is not for free and there has to be paid option premium. It is price for risk connected with transaction. Options are traded on exchanges and in the over-the-counter market.

Holder of call option has right to buy underlying asset for certain price in certain time. Holder of put option has right to sell underlying asset for certain price in certain time.

Price of option is option premium which buyer pays to seller. Option premium with other fees and commissions represents costs of options right and determines value of maximum loss for buyer of option and maximal potential profit for seller of option at the same time.

If the option can be exercised only at the end of its life we call this option European option, if there is possibility to exercise option anytime during option's lifetime we call this option American option. American options are usually used in equities and European options in commodities.

Intrinsic value

Intrinsic option value shows us how advantageous is to exercise option immediately. It is relation between exercise price (X) and underlying asset price (S_t). Intrinsic value is profit which holder would gain with immediate option exercising and simultaneously compensating trade at the spot market. Option has intrinsic value only in case when this profitable transaction can be done.

There are three possible states in call option lifetime:

- if $S_t > X$ intrinsic value of option is $S_t - X$ and option is in the money (*ITM*). In this case holder of option can buy underlying asset cheaper than at spot market and gain profit by immediate sale for current rate.

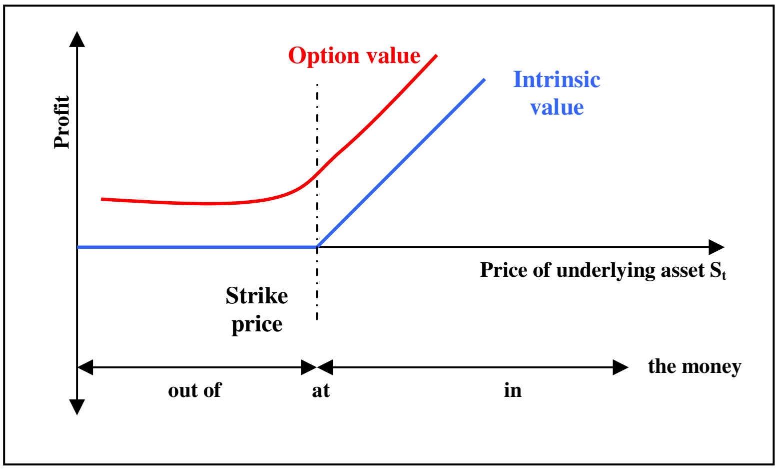
- If $S_t = X$ intrinsic value of option is zero and option is at the money (*ATM*). In this case it does not matter if holder of option exercises option or not, there is no loss and no gain.

- If $S_t < X$ intrinsic value of option is zero and option is out the money (*OTM*). It is situation when holder of option can suffer loss if he exercises option immediately. Current market underlying asset price is lower than price agreed in option contract increased with option premium.

Time value

Time value is difference between option value and intrinsic value. If the time value is negative it is good to sell the option. It can be done only if holder has American option which can be exercised anytime during option lifetime.

Figure 3.8: Value before expiration at time t



3.6.1 Factors influencing option value

Every asset's price traded on a market is determined by supply and demand. It is not different with price of option. However, there are few other factors can play a role in the pricing of option. There are six major factors which influence value of option, either call or put. It is price of underlying asset, strike price, time to maturity, volatility, dividends and risk-free interest rate. Basic presumption is constancy of all other factors but as we know it is not possible in reality and we have to consider cohesion of individual factors.

First factor influencing option value is price of underlying asset (S_t). Every change, even the small one, is reflected by a change in the price of option. Changes in prices of underlying assets have opposite effects on puts and calls. When price S_t grows it means that intrinsic value of call option grows as well.

Strike price (X) also known as exercise price is agreed when contract is made. Call option with lower strike price has higher option premium than those whose strike price is high. This is caused because lower strike price causes increased probability of using of option and with increased probability increase price of option.

Among agreed contract terms is settled, except the strike price, time until maturity as well. Further the time is the bigger probability that price of underlying asset may change and option writer undergoes higher level of potential loss. That is why option premium is bigger for longer maturity times. It less probable that underlying asset price is going to change radically in short period of time thus the premium is lower.

Underlying asset price volatility is also bounded with time to maturity. Volatility expresses deviation of underlying asset price from their mean value. High volatility is not expected when we have short time to maturity and option premium is lower. But if we have longer time to maturity, for example several months, underlying asset price can go up and down several times. Option holder can gain high profits and on the other hand option writer can gain high losses and it appears from this that option premium is higher due to high potential risk level.

All other conditions being equal increase of interest rate will have negative influence on put option price and positive influence on call option price. This has simple explanation. Buyer of call option pays strike price in maturity time and till than he can invest that amount and gain interest. On the other hand owner of put option has to keep underlying asset until maturity time and is loosing potential interest. As in other cases time to maturity plays significant role here because options with shorter time to maturity are not so sensitive to interest rate changes.

Dividends are received by owning shares outright. Holder of option cannot gain dividend yield. Dividends causes decrease in price and it can be expected that call option premium will be lower when there is expectation of higher dividend yield. And vice versa put option premium will be higher when there is same expectation. Not only equities can be used. In case of foreign exchange option dividend yield is worth the foreign interest rate.

Influence of all factors on call and put option is summarized in Figure 3.9.

Figure 3.9: Influence of factors on option price

Increase of factor	Price	
	Call option	**Put option**
Underlying asset price	↑	↓
Strike price	↓	↑
Time to maturity	↑	↑
Volatility	↑	↑
Risk-free interest rate	↑	↓
Dividends	↓	↑

3.6.2 Pricing of options

Black-Scholes model was firstly published in 1973 by Fisher Black and Myron Scholes. "The Pricing of Options and Corporate Liabilities" paper was one of the turning points in economy and it offered elegant closed-form solution for European options pricing.

Financial markets environment is relatively complicated so authors tried to simplify it with these presumptions:

- The price of the underlying asset moves in a continuous fashion.
- Interest rate is known, risk-free and constant.
- Prices have log-normal distribution.
- Perfect capital market[9]
- Equity prices follow geometric Brownian motion with constant drift and volatility.
- Prices are independent on expected returns, independent in time.
- The stock pays no dividends or other distributions.

Under these presumptions can be European call option determined by

$$c = S_0 \cdot N(d_1) - e^{-r \cdot dt} \cdot X \cdot N(d_2), \tag{3.32}$$

where

$$d_1 = \frac{\ln\left(\frac{S_0}{X}\right) + \left(r + \frac{\sigma^2}{2}\right) \cdot dt}{\sigma \cdot \sqrt{dt}} \tag{3.33}$$

and

$$d_2 = d_1 - \sigma \cdot \sqrt{dt}, \tag{3.34}$$

where c is price of European call option, S_0 is the spot price of underlying asset, X is the strike price, r is the risk-free interest rate p.a., dt is time to maturity, $dt = T - t_0$, σ is

[9] There is possibility of shot selling, there are no transaction costs or taxes, no liquidity problems, market operates continuously.

standard deviation of underlying asset return, $N(\cdot)$ is cumulative normal distribution function and $e^{-r\cdot dt}$ is continuous-time discount factor.

Price of European put option may be derived from put-call parity which is relation between European call and put options[10] given by

$$c + e^{-r\cdot dt} \cdot X = p + S_0. \tag{3.35}$$

Value of put option is then as follows

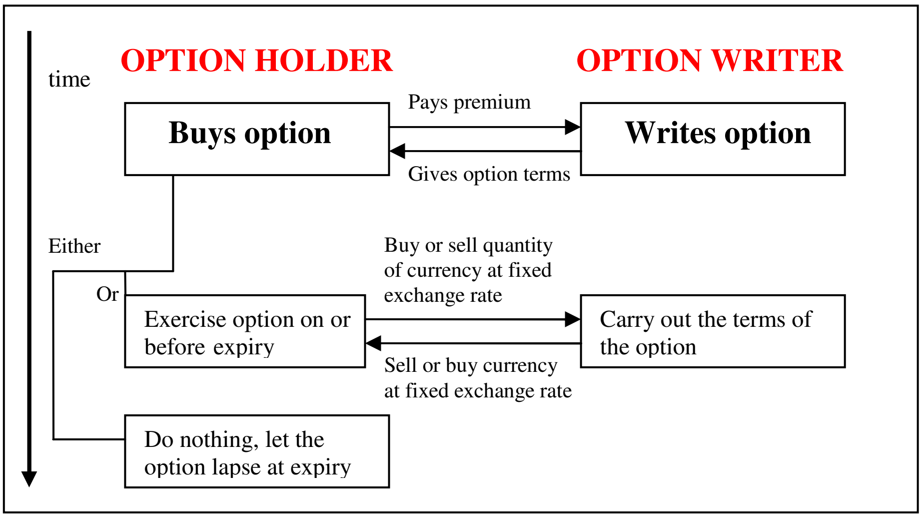
$$p = X \cdot e^{-r\cdot dt} \cdot N(-d_2) - S_0 \cdot N(-d_1), \tag{3.36}$$

where p is price of European put option.

3.6.3 Currency option

Currency option has as underlying asset exchange rate. Figure 3.10 displays system of currency option.

Figure 3.10: Currency option



For FX option pricing we have to use different model because Black-Scholes model is for options where the underlying asset is non-dividend-paying stock. In 1983 Mark Garman and Steven Kohlhagen published paper "Foreign Currency Option Values" which provides an analytic valuation model for European options on currencies.

The presumptions are the same as in the Black-Scholes model only presumption of borrowing and lending does not take place at the same interest rate due to two currencies thus there will be two interest rates – domestic and foreign.

[10] European put and call options must have for this relation same maturity, strike price and have to be bounded with the same underlying asset.

FX call option is formulated as follows

$$c = e^{-r_f \cdot dt} \cdot S \cdot N(d_1) - e^{-r_d \cdot dt} \cdot X \cdot N(d_2), \tag{3.37}$$

where r_f is the foreign risk-free interest rate, r_d is the domestic risk-free interest rate and

$$d_1 = \frac{\ln(S/X) + \left[r_d - r_f - (\frac{\sigma^2}{2}) \right] \cdot dt}{\sigma \cdot \sqrt{dt}}, \tag{3.38}$$

$$d_2 = d_1 - \sigma \cdot \sqrt{T}. \tag{3.39}$$

For FX put option is price given by

$$p = e^{-r_d \cdot dt} \cdot X \cdot N(-d_2) - e^{-r_f \cdot dt} \cdot S \cdot N(-d_1). \tag{3.40}$$

3.6.4 Basic option positions

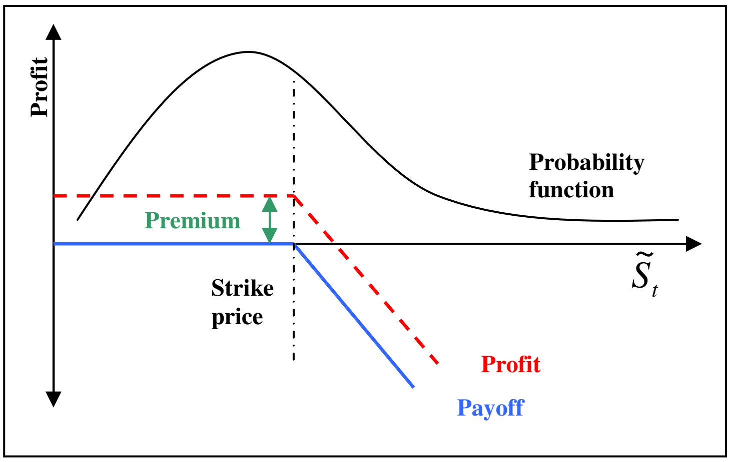
There are four basic positions in which the option trade can be made. Their payoffs and profits are displayed in Tab 3.4.

Short call (selling of call option)

Seller (investor in short call position) has an obligation to buy for pre-agreed price agreed amount of underlying asset if the buyer of call option exercises the option. There is paid option premium by the buyer. Seller of the option can gain maximum profit equal to the option premium amount.

When the price of underlying asset is increasing he can gain unlimited loss because he has to fulfil his obligation, we can see this effect in Figure 3.11.

Figure 3.11: Short call payoff and profit function

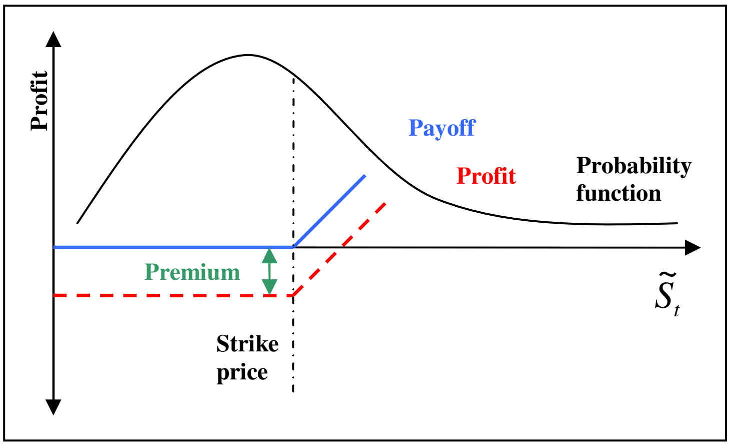


Long call (buying of call option)

Buyer has the right but no obligation to buy for pre-agreed price agreed amount of underlying asset. Option premium has to be paid for this right.

From the Figure 3.12 we can see that maximum loss of buyer is equal to option premium which he paid to the seller of option. This can happened when underlying asset price decrease so much that it is not profitable to exercise option. On the other hand owner of option can gain unlimited profit with increasing value of asset.

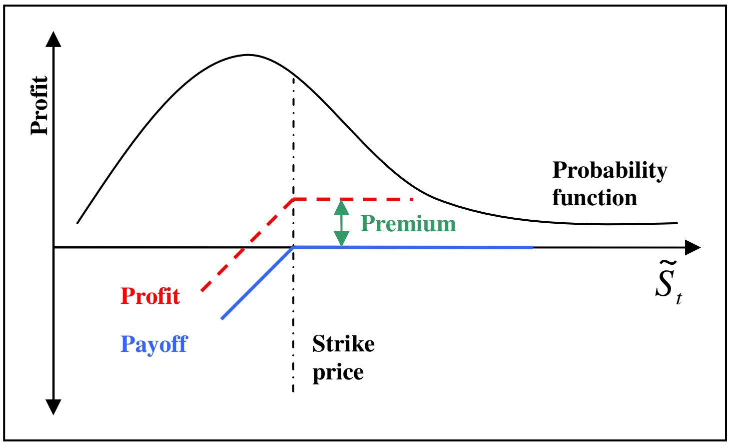
Figure 3.12: Long call payoff and profit function



Short put (selling of put option)

Seller of option has the obligation to buy agreed amount of underlying asset for pre-agreed price in buyer of option exercise an option. Buyer pays option premium to the seller. We can see in Figure 3.13 that maximum profit of the seller is equal to option premium and loss is unlimited because of an obligation.

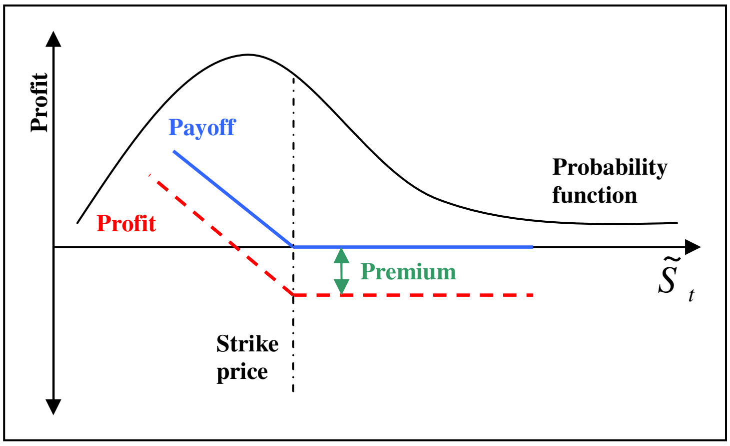
Figure 3.13: Short put payoff and profit function



Long put (buying of call option)

Buyer of option has right to sell agreed amount of underlying asset for pre-agreed price. This right is charged and buyer has to pay option premium to the seller. Option premium is also maximum potential loss of buyer. Profit is in case of increasing underlying asset price unlimited. Figure 3.14 displays profit and payoff of long put.

Figure 3.14: Long put payoff and profit function



In the following table we can see payoffs and profits of presented option positions.

Tab 3.4: Payoffs and profits of options

Option	**Buyer**		**Seller**	
	Payoff	Profit	Payoff	Profit
Call option	$\max(S_T - X;0)$	$\max(S_T - X - c;-c)$	$\min(X - S_T;0)$	$\min(X - S_T + c;c)$
Put option	$\max(X - S_T;0)$	$\max(X - S_T - c;c)$	$\min(S_T - X;0)$	$\min(S_T - X + c;c)$

3.6.5 Option types and strategies

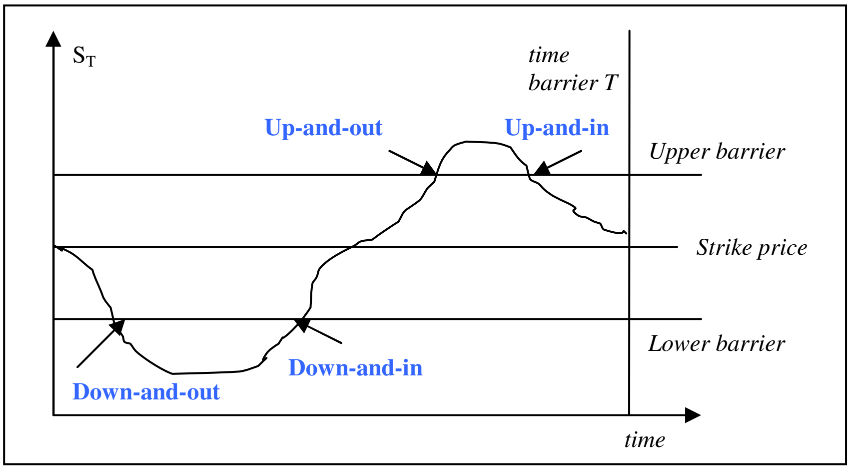
Barrier options

Barrier option is exotic option which is very popular among forex option traders. This option is generally cheaper than plain vanilla option. This is caused by the fact that barrier option may never come into effect or may be cancelled. Its payoff depends on whether the price of underlying asset reaches certain level during a certain period of time. Payoff depends on time and current spot price but the fact if the option is in time of maturity active or passive is influenced by previous evolution of underlying asset price. If the option is active it means that it is exercisable and if the option is passive, we cannot exercise the option.

If the underlying asset price reaches a certain barrier, *knock-out* option ceases to exist and is passive from that moment but *knock-in* option starts to exist and is active.

Figure 3.15 displays four basic types of barriers which can exist individually, these are simple barrier options, or in combination, these are complicated barrier options, for example there can be contract where counterparties agreed on option with *up-and-out* and *down-and-out* barrier. Of course these options may be either call or put.

Figure 3.15: Barrier option



Furthermore we can have fixed barriers for the option life time or changing and we can observe underlying asset price continuously or discretely so there can be finite or infinite number of time moments when the option may start or stop to exist.

Barrier option pricing

Prices for down-and-in call option and down-and-out call option are given by following relations.

1) In case that barrier H is lower or equal to exercise price X, $H \leq X$

$$c_{di} = S_0 \cdot e^{-r_f \cdot T} \left(\frac{H}{S_0} \right)^{2\lambda} \cdot N(y) - X \cdot e^{-r_d \cdot T} \cdot \left(\frac{H}{S_0} \right)^{2\lambda - 2} \cdot N(y - \sigma\sqrt{T}). \tag{3.41}$$

where

$$\lambda = \frac{r_d - r_f + \frac{\sigma^2}{2}}{\sigma^2}, \tag{3.42}$$

$$y = \frac{\ln\left[H^2 / (S_0 \cdot X)\right]}{\sigma \cdot \sqrt{T}} + \lambda \cdot \sigma \cdot \sqrt{T}. \tag{3.43}$$

Because the value of call option is equal to sum of down-and-in call option and down-and-out call option then the value of down-and-out call option is given by

$$c_{do} = c - c_{di}, \tag{3.44}$$

2) In case that barrier H is bigger or equal to exercise price X, $H \geq X$

$$c_{do} = S_0 \cdot N(x_1) \cdot e^{-r_f \cdot T} - K \cdot e^{-r_d \cdot T} \cdot N(x_1 - \sigma \cdot \sqrt{T})$$
$$- S_0 \cdot e^{-r_f \cdot T} \left(\frac{H}{S_0} \right)^{2\lambda} \cdot N(y_1) + X \cdot e^{-r_d \cdot T} \cdot \left(\frac{H}{S_0} \right)^{2\lambda - 2} \cdot N(y_1 - \sigma \cdot \sqrt{T}), \tag{3.45}$$

where
$$x_1 = \frac{\ln\left(\frac{S_0}{H} \right)}{\sigma \cdot \sqrt{T}} + \lambda \cdot \sigma \cdot \sqrt{T}, \tag{3.46}$$

$$y_1 = \frac{\ln\left(\frac{H}{S_0} \right)}{\sigma \cdot \sqrt{T}} + \lambda \cdot \sigma \cdot \sqrt{T}. \tag{3.47}$$

Price of down-and-in call option is given by
$$c_{di} = c - c_{do}. \tag{3.48}$$

Prices of up-and-in call option and up-and-out call option are given by following formulas.

1) In case that barrier H is bigger than exercise price X, $H > X$

$$c_{ui} = S_0 \cdot N(x_1) \cdot e^{-r_f \cdot T} - X \cdot e^{-r_d \cdot T} \cdot N(x_1 - \sigma \cdot \sqrt{T}) - S_0 \cdot e^{-r_f \cdot T} \cdot \left(\frac{H}{S_0} \right)^{2\lambda} \cdot$$
$$\left[N(-y) - N(-y_1) \right] + e^{-r_d \cdot T} \cdot \left(\frac{H}{S_0} \right)^{2\lambda - 2} \cdot \left[N(-y + \sigma \cdot \sqrt{T}) - N(-y_1 + \sigma \cdot \sqrt{T}) \right], \tag{3.49}$$

and for up-and-out call option
$$c_{ou} = c - c_{ui}. \tag{3.50}$$

In case that barrier H is lower or equal to exercise price X, $H \leq X$
$$c_{uo} = 0, \tag{3.51}$$
$$c_{ui} = c. \tag{3.52}$$

Binary options

Binary option also called digital option is similar to barrier option. It is type of exotic option where the condition for payoff is something else than just the price and the expiration date. Payoff is nothing or all, it does not depend on the difference between St and K. Holder of binary option receives payoff in case that the underlying asset price is at the expiration date T above the strike price. This type of option is called *cash-or-nothing* call. Also there is a possibility to have option where the underlying asset price can overreach strike price whenever during the option life time. Options may be call or put.

Another type of binary option is *asset-or-nothing*. Payoff of this option is not in cash but amount equal to the asset price.

Pricing of binary option

Prices of cash-or-nothing call and put option are given as follows

$$c_{cn} = Q \cdot e^{-r_d \cdot T} \cdot N(d_2), \tag{3.53}$$

$$p_{cn} = Q \cdot e^{-r_d \cdot T} \cdot N(-d_2), \tag{3.54}$$

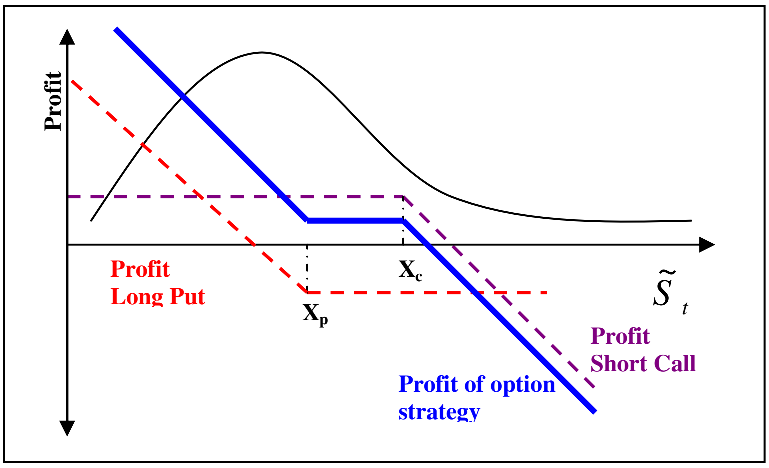
where Q is pre-agreed amount and $N(d_2)$ interprets probability that option will be exercised.

Risk Reversal

Risk Reversal strategy represents combination of long put and short call option with the same underlying asset with the same maturity time and different exercise price. Another option is to have two exercise prices – one for put and second for call option, but different quantities.

Investor is covered by this strategy against decrease in the price of underlying asset, in our case exchange rate of CZK/EUR or CZK/USD, or increase in that price. We can see this effect in the following Figure 3.16.

Figure 3.16: Risk Reversal strategy



4 Verification and evaluation of chosen hedging strategies

This part of thesis results from theoretical knowledge referring to information obtained from financial manager of BorsodChem company and issue of risk management and derivatives hedging.

There will be verified and compared different risk hedging strategies. As we know from Chapter 2, most of the company's transactions are realized abroad. 97% of profit flows from foreign countries. Payments and clearing system(platební styk) are done in three currencies – CZK, EUR and USD. Most of the strategies will be used for EUR hedging but few of them will be counted for USD as well to see the difference between positions, e.g. call and put option.

The company is in long position when we talk about EUR which means that there is a fear about decreasing exchange rate. USD represent company's cost for transport and gas and because there is not enough revenues in USD, company is in short position.

Following strategies will be applied.

a) Passive strategy – Company is not doing any hedging during whole year and the amount of money is changed in time t_n $(n = 1,2,3...12)$ for current spot rate S_n.
b) Forward contract with 1 month maturity time - Company enters the forward contract every month from time t_0 till t_{12} and buys agreed amount for agreed exchange rate.
c) Forward contract with maturity time longer than 1 month - Company enters the forward contracts for 12 month in advance in time t_0.
d) Swap contract – It is contract composed from the portfolio of forward contracts.
e) Plain vanilla option contract – Company buys option contract in time t_0 and does not do anything whole year. It is a form of static hedging.
f) Delta hedging – There is created a hedging portfolio consisted of forward contracts.
g) Risk reversal strategy – It is a combination of sold call option and bought put option with the same maturity time, the same underlying asset, the same quantity but different exercise prices of put option. Option premiums are eliminated which means that it is a zero cost strategy.
h) Risk reversal II. – It is the same combination of options. The difference is in quantity which is different for both options thus the constraints are slightly changed.

After applying certain strategy, there will be counted effect which is either gain or loss. This effect will be divided into 20 intervals where every interval represents percentage appearance of effect. Hedging effect will be counted as annual profit or loss from those strategies. In the end every strategy displays figure of probability distribution function where we can see effect in case of using strategy in certain interval.

Individual strategies will be in the end evaluated according these criteria:

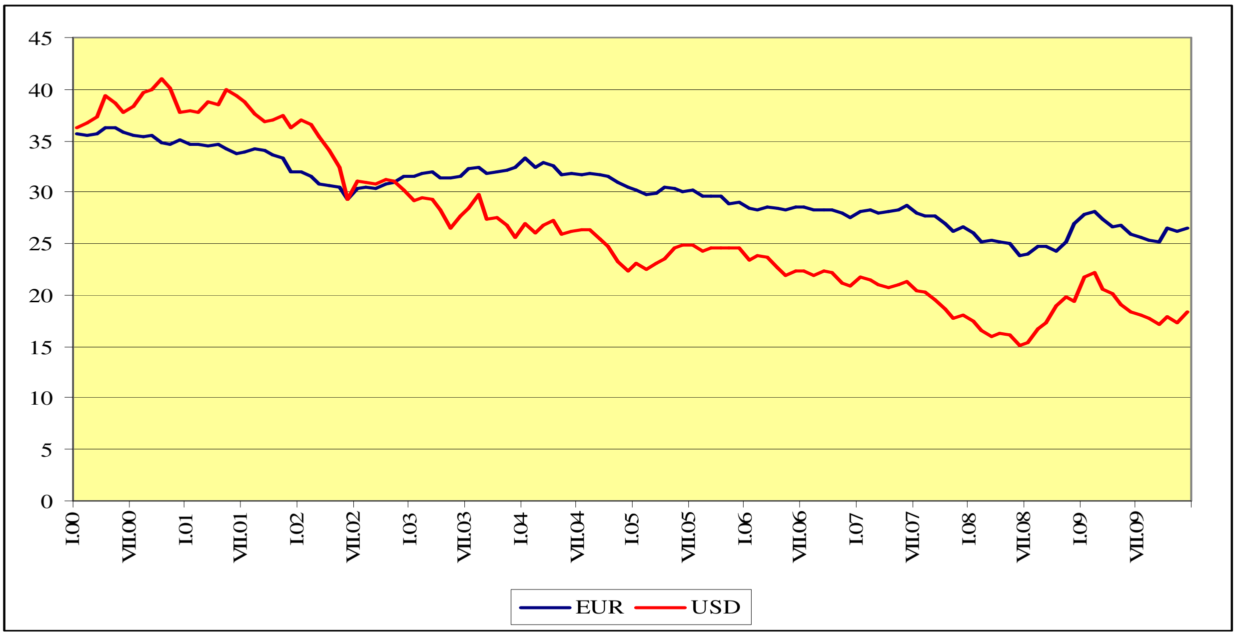
- standard deviation which expresses measure of average value distance from their standard deviation;
- mean value which represents random variable distribution, weighted average of given data set;
- the best result where the highest value of data set is found;
- the worst result where the lowest value of data set is found;
- 5% quantile;
- 50% quantile.

Criteria will be compared for individual strategies and then the strategies will be evaluated from the return-risk point of view, entering capital requirements and availability of strategies.

4.1 Volatility forecast of exchange rate CZK/EUR and CZK/USD

Input data for volatility forecast are obtained as historical time series from ARAD database provided by Czech National Bank (ČNB) in December 2009. As mentioned before if we want to have successful forecast there is necessary at least 70 data, in this forecast there is 120 data from January 2000 till December 2009. To gain precision of forecast there was not used monthly averages but data around the end of each month so the random fluctuations are pictured better than in case of averages. Historical trend can be seen in Figure 4.1.

Figure 4.1: Historical trend of CZK/EUR and CZK/USD[11]



There is used EWMA model that was described in Chapter 3 for volatility forecast. Firstly there were counted continuous yields (R_t) according to (3.5). Mean value is for CZK/EUR -0,00382 and -0,00672 in case of CZK/USD so this value was modified. It means that this mean value is deducted from continuous yields and continuous adjusted yields are obtained. Now the mean value is zero. Another step is to calculate observed variance as squared monthly continuous adjusted returns (ε_t^2). Forecasted variance for CZK/EUR rate at the moment *t* for the time *t+1*, ($\sigma_{t+1,t}^2$) is calculated according to formula (3.3).

The variance and covariance calculation is done through analytical tool *Solver* in MS Excel program. Objective function is set on minimization a RMSE criterion (3.4). There is one condition and that is the interval (0; 1) where (λ) must fluctuate.

Value of decay factor is according to *Solver* calculated as 1, it means that homoscedasticity, constant variance, is present which means that future trend of CZK/EUR rate will be not affected by past data series.

As result from this data series of 120 observations monthly variance is 0,000307 and according to

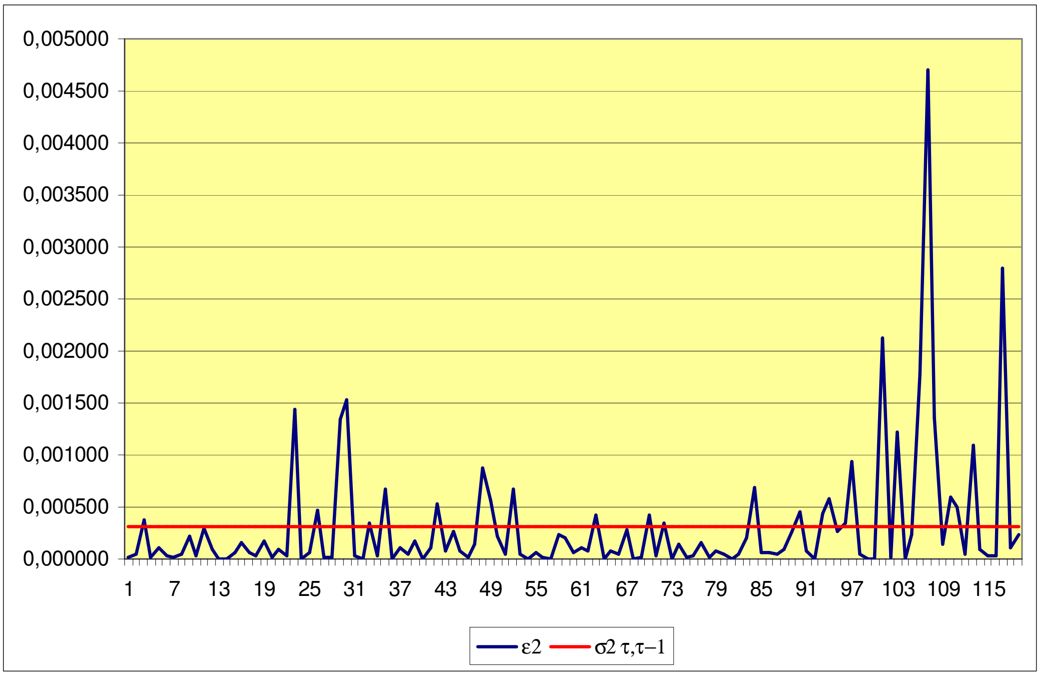
$$\sigma_{t+1,t} = \sqrt{T \cdot \sigma_{t+1}^t} \tag{4.1}$$

[11] As we can see, in the beginning of observed period value of CZK/USD was higher than CZK/EUR. Final decrease was caused by uncertain political situation as well as unwillingness of American firms to invest money, make new job opportunities or accept new employees. In year 2002 there was huge number of bankrupt companies which had significant impact on their economy.

is annual variance equal to 0,060696.

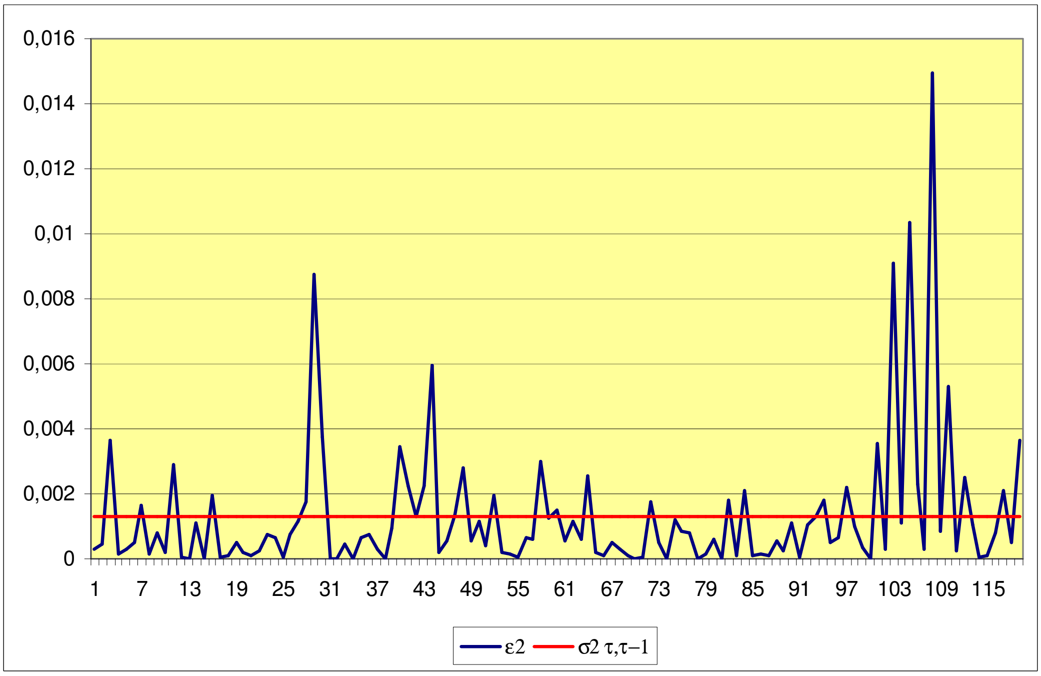
Following Figure 4.2 displays variance trend of CZK/EUR rate.

Figure 4.2: Variance trend of CZK/EUR rate according to EWMA



Monthly variance of US dollar is 0,0012924 and annual variance reaches the level of 0,124534. Estimated variance for CZK/USD is displayed in Figure 4.3.

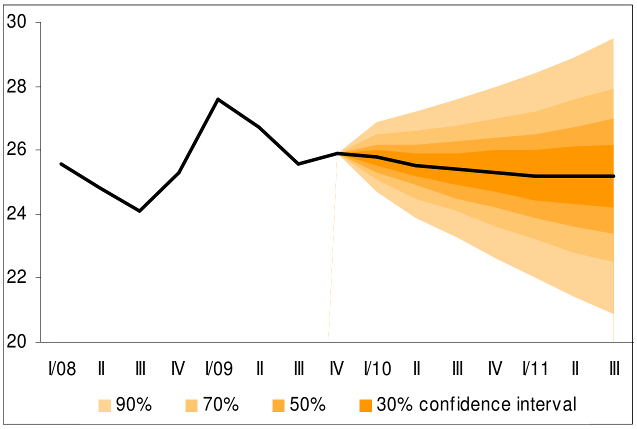
Figure 4.3: Variance trend of CZK/USD rate according to EWMA



4.2 Exchange rate forecast

Czech National Bank has been forecasting CZK/EUR movement from the last quarter of 2008. Main purpose of that was to have maximal transparency and be able to forecast monetary policy. Figure 4.4 displays the uncertainty in the future development of currency rate CZK/EUR. The darkest band around the central projection corresponds to the development in 30% of possible scenarios of future and the others have same explanation but other percentage. For 2010 there is 25,50CZK/EUR forecast from Czech National Bank.

Figure 4.4: EUR/CZK forecast in 2010



Source: www.cnb.cz

This forecast is going to show us the difference between bank forecast and Monte Carlo simulation forecast. Bank forecast is better to use in short-term point of view but since we are predicting evolution of CZK/EUR and CZK/USD for one year we will use Monte Carlo simulation. Another problem is that Czech National Bank publishes only quarterly forecast with one exchange rate forecasted for whole year whilst we need forecast for every single month in 2010.

Financial assets as well as exchange rates have in time random evolution. Since exchange rates does not have tendency to revert back to some average, we can exclude so-called mean reversion models which are characteristic for interest rate. Simulation of exchange rate is applied geometric Brownian motion and Monte Carlo simulation.

We generate random values (z) from the standard normal distribution for each scenario. The procedure is done by means of the Random Number Generation in the MS Excel program. Mean value is 0 and standard deviation is 1 for 12 variables and 500 random numbers. In total we obtain 6000 random numbers where every trial has 12 steps and interprets exchange rate evolution for each month in 2010.

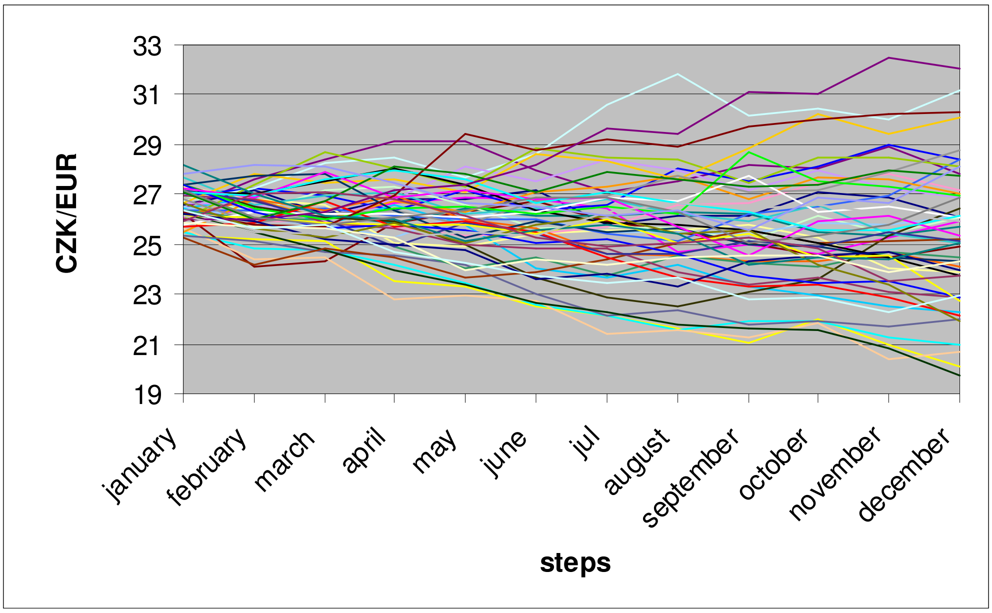
The input data obtained from historical data series and used for simulations are in Tab 4.1.

Tab 4.1: The input data

Parameters	Symbol	CZK/EUR	CZK/USD
Mean value	μ	-0,002523181	-0,005716572
Standard deviation	σ	0,017512343	0,03595
Interval	*t*	1	1
Currency rate in time t	S_0	26,47	18,37
Number of steps	*N*	12	12

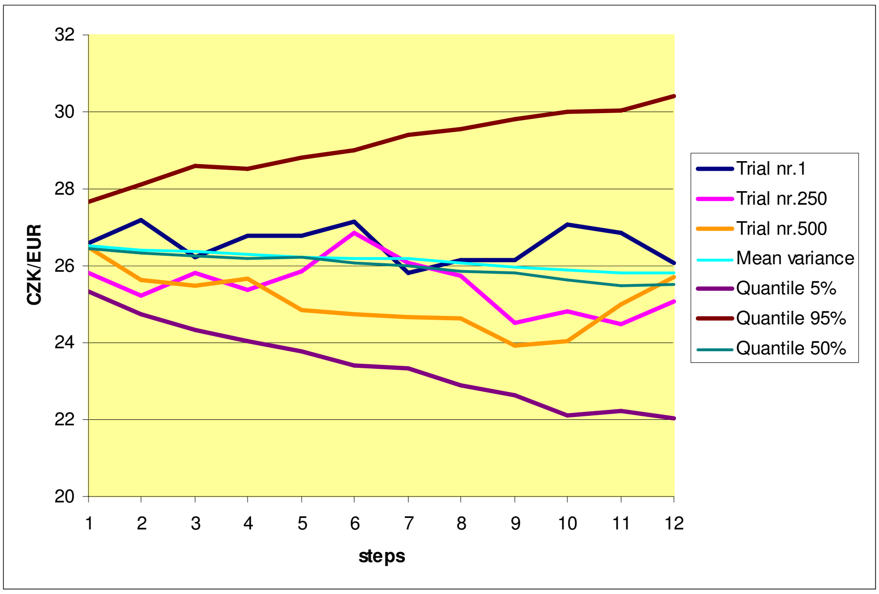
Figure 4.5 displays 30 trials just for imagination because whole set of 500 trials is not providing an easy survey.

Figure 4.5: CZK/EUR evolution in 2010



Mean variance (μ), standard deviation (σ), quantile 5%, quantile 50% and quantile 95% were counted for simulated currency rate evolution are displayed in Figure 4.6.

Figure 4.6: Random exchange rate CZK/EUR evolution



Some of the strategies will be used for hedging of US dollar cash flows as well. CZK/USD evolution for 2010 is displayed in the Supplement 4. The input parameters are according to Tab 4.1 following:

- standard deviation $\sigma = 0{,}035949525$;
- current exchange rate in time t_0, $S_0 = 18{,}37\, CZK / USD$;
- risk-free interest rate of home country $r_d = 2{,}13\%$;
- risk-free interest rate of foreign country $r_f = 2{,}02\%$.

Risk-free interest rate for US dollar is taken from US Department of the Treasury and there was chosen Long Term Real Rate Average which was 2,02% on 31st December 2009.

The results of pricing of chosen strategies are in the Supplement 5 because of their similar calculation, the evaluation is then described in the Chapter 4.4. Any change in calculation between EUR and US dollar strategy is described in the following chapter.

4.3 Application of hedging strategies for EUR

4.3.1 Passive strategy

If the company faces currency risk but it does not hedge to eliminate it completely or at least decrease that risk then the company takes passive strategy and is in uncovered position. Every month just simply changes the amount of EUR 5 million for current spot rate and the effect from this transaction is following

$$effect_t = Q \cdot (S_t - S_0), \tag{4.2}$$

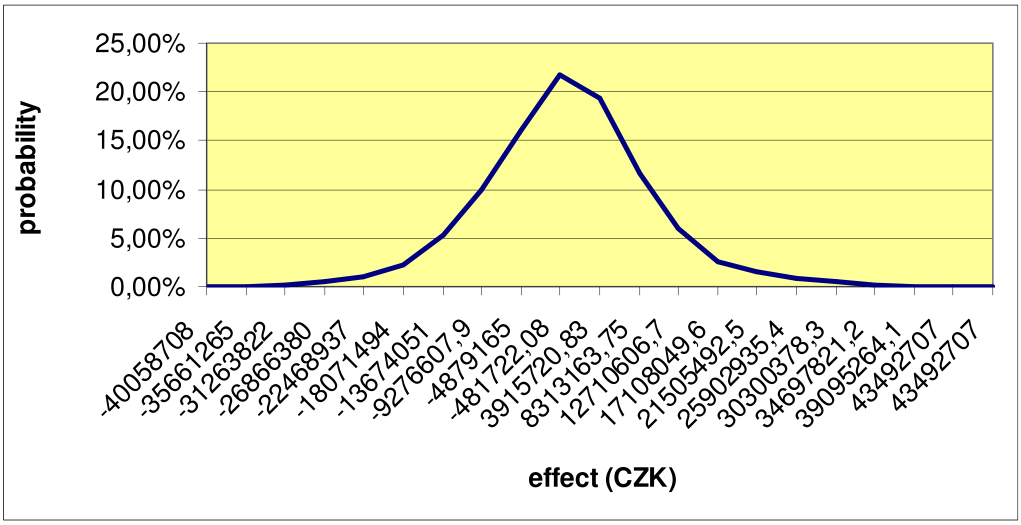
where Q represents monthly amount of EUR 5 million, S_t is current spot rate in time t and S_0 is exchange rate in time $t-0$.

S_t represents in calculation values obtained by using Monte Carlo simulation. S_0 is constant at the level 26,47 CZK/EUR.

Gain of loss of this transaction depends on current exchange rate in time t. If S_t is lower than S_0, which means that Czech crown is strengthening, it means loss for the company. On the other hand when Czech crown is weakening and S_t is bigger than S_0, company gains profit.

Following Figure 4.7 displays probability distribution of effect from this strategy for all 6000 trials for 2010.

Figure 4.7: Probability distribution for passive strategy



When we count with monthly exchange of 5 mil EUR than the total result is loss in the range from -61 893 thousand CZK till – 31 316 thousand CZK in 13,80% of the cases of all trials. The company can gain profit only in 38,80% of the cases of all simulated rates.

4.3.2 Pricing of forward contract with 1 month maturity time

If the company does not want to hedge their cash flows for whole year there is possibility of entering forward contract for each month extra. Exercise price is counted according to (3.30).

Then currency forwards are counted for every month. Current exchange rate in time t_0 is from the second month changed by forecasted exchange rate. This process is repeated for all 500 trials.

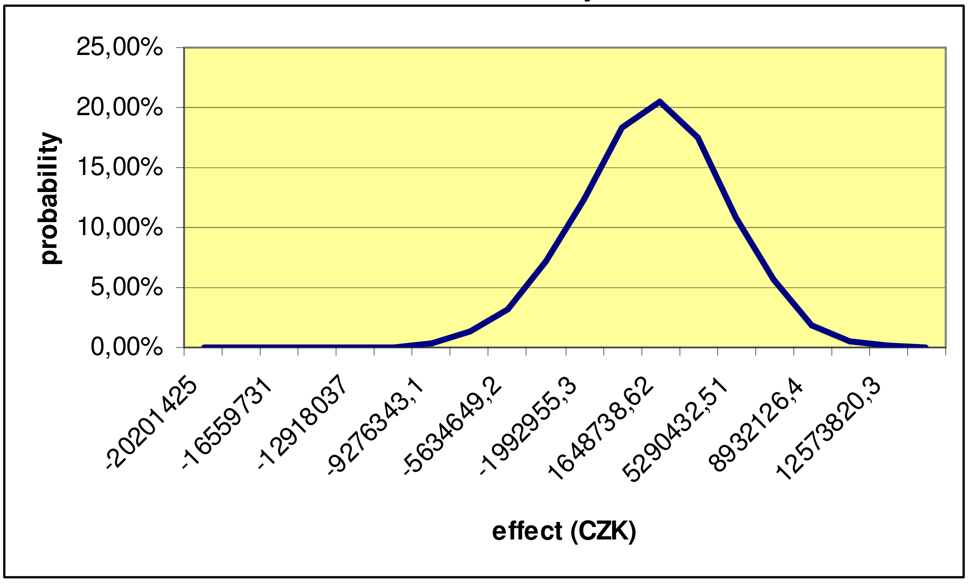
After that we count difference between forward and predicted rates and result is multiplied by quantity of exchanged currency. Monthly differences are result of this process, we count them together to get annual values and obtain necessary calculations such as standard deviation or minimal value.

Parameters for pricing of currency forward are following:

- current exchange rate in time t_0, $S_0 = 26{,}47\, CZK / EUR$, then the spot rate is changed every month according to forecasted values;
- risk-free interest rate of home country $r_d = 2{,}13\%$;
- risk-free interest rate of foreign country $r_f = 1{,}248\%$;
- time to maturity $(T - t) = 1$ month (1/12).

We can see in Figure 4.8 probability distribution obtained by using this forward strategy.

Figure 4.8: Probability distribution of forward contract with 1 month maturity time



Annual result of this strategy will be in the case of contract settling in 20,53% either loss in the range of <-171 thousand CZK;0> or profit in the range of <0;1648 thousand CZK>. Profit is gain in 57,23% of the cases.

4.3.3 Pricing of forward contract with longer maturity time

This contract is similar to the previous one but company is buying in time t_0 forward contracts for whole year in advance. Each of them has different maturity time, first contract is expiring at the end of January (1/12), second one at the end of February (2/12) and the twelfth one will expire at the end of December (12/12). The rest is the same as in case of forward contract for each month extra.

Firstly we count exercise price according to (3.30) as $X = S_t \cdot e^{(r_d - r_f)\cdot(T-t)}$. Then currency forwards for whole year but still with spot rate S_0 and different maturity times. Again this process is repeated for all trials. Forward rates are displayed in Tab 4.2.

Parameters for pricing of currency forward are following:

- current exchange rate in time t_0, $S_0 = 26{,}47\, CZK / EUR$;
- risk-free interest rate of home country $r_d = 2{,}13\%$;
- risk-free interest rate of foreign country $r_f = 1{,}248\%$;
- time to maturity $(T - t) = 1$ month (1/12)...12 month (12/12).

Home country risk-free interest rate is represented by Pribor and foreign country risk-free interest rate by 1 year Euribor.

Tab 4.2: Forward contract rates for different maturity times (in CZK)

1	2	3	4	5	6	7	8	9	10	11	12
26,489	26,509	26,528	26,548	26,568	26,587	26,607	26,626	26,646	26,665	26,685	26,705

Effect gained by using forward hedging strategy is given by

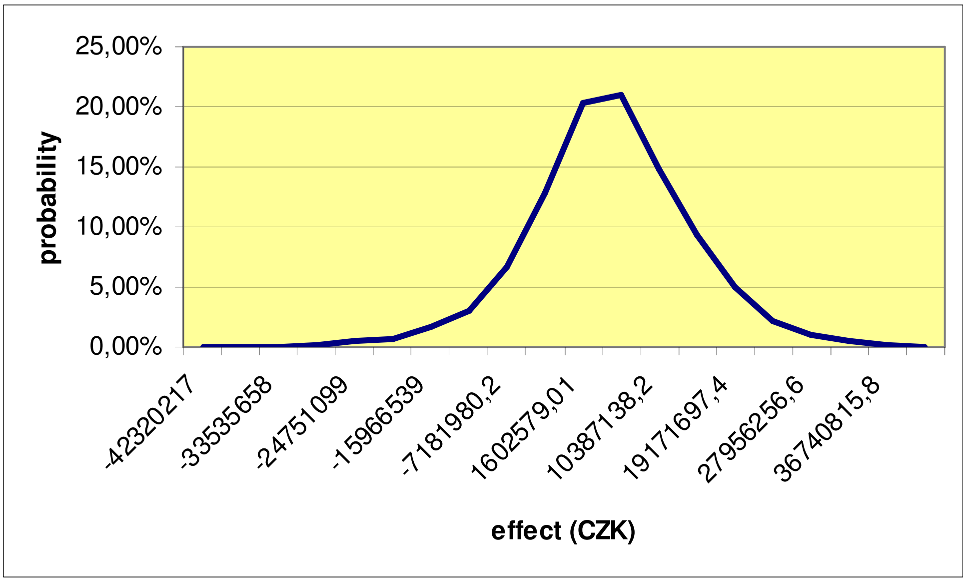
$$\begin{aligned} effect_t &= Q \cdot (F_t - S_t), \\ where\ t &= [1,2,3,\ldots,12], \end{aligned} \tag{4.3}$$

where Q is monthly amount of EUR 5 000 000, F_t is forward rate for contract with maturity time t and S_t is current spot rate in time t.

Company is gaining profit in case that forward rate is bigger than current spot rate. Whole hedging effect for 2010 is displayed in Figure 4.9.

Conversion of 5 mil EUR monthly will bring annual profit in the range from 1 603 thousand CZK till 5 994 thousand CZK. Profit is gained in 74,43% of all cases.

Figure 4.9: Probability distribution of forward contract with longer maturity time



4.3.4 Swap

It is similar situation as forward contracts settled individually for each month. Every month has different maturity time because swap is contract composed of 12 different forwards. It is counted for all 500 trials. Firstly exercise price is counted according to the following formula

$$sw_{t,T} = \sum_{i=1}^{T} f_{t,t_i} \tag{4.4}$$

When we replace f_{t,t_i} from (4.4) then we get

$$sw_{t,T} = \sum_{t_i}^{T} (X \cdot e^{-r_d \cdot (T-t)} - S_t \cdot e^{-r_f \cdot (T-t)}), \tag{4.5}$$

where $sw_{t,T}$ is price of forward contract, S_t is current spot rate and $f_{t,ti}$ is forward contract price with delivery time t_i.

Exercise price of swap contract is in time of settling determined by assumption $sw_{t,T} = 0,$ which means that following relation has to be valid

$$\sum_{t_i}^{T} X \cdot e^{-r_d \cdot (T-t)} = \sum_{t_i}^{T} S_t \cdot e^{-r_f \cdot (T-t)}. \tag{4.6}$$

Delivery price is than given by

$$F_0 \equiv X_0 = S_t \cdot \frac{\sum_{t_i}^{T} e^{-r_f \cdot (t_i - t)}}{\sum_{t_i}^{T} e^{-r_d \cdot (t_i - t)}}. \tag{4.7}$$

The input parameters are the same as in case of forward strategies. After giving unknowns into (4.7) we get $X = 26{,}4425\, CZK / EUR$.

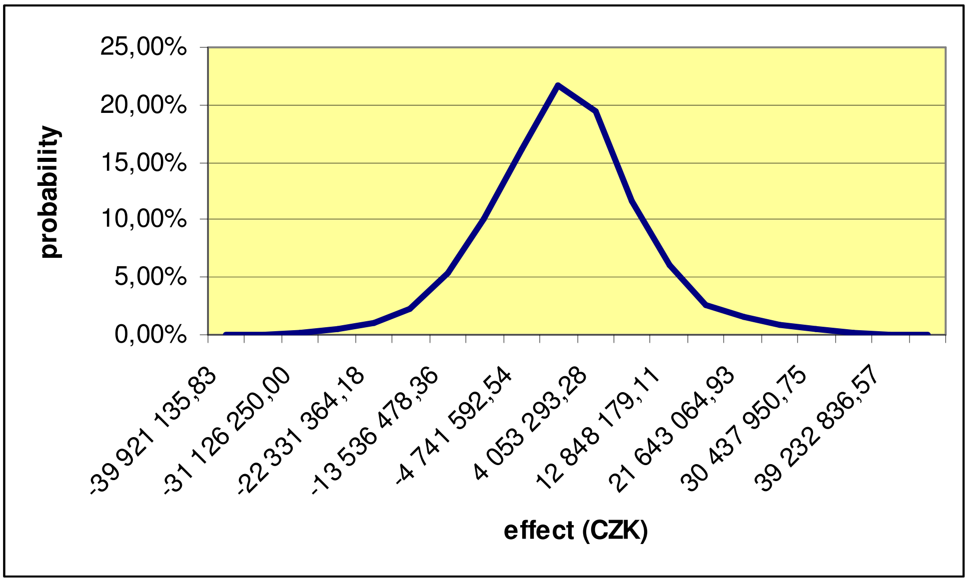
Hedging effect gained by using this swap strategy is given by

$$\begin{aligned} effect_t &= Q \cdot (sw_{t,T} - S_t), \\ where\ t &= [1,2,3,\ldots,12], \end{aligned} \tag{4.8}$$

where Q is monthly amount of EUR 5 000 000, $sw_{t,T}$ is swap rate for contract with maturity time t and S_t is current spot rate in time t.

If the current spot rate will be higher than exercise price then the company losses and this contract is not profitable. In case of Czech crown strengthening is the company gaining profit; it means that current spot rate is lower than exercise price. Probability distribution of this strategy is displayed in Figure 4.10.

Figure 4.10: Probability distribution of swap contract



Loss of the range <-4740 thousand CZK; -344 thousand CZK> will be gained in 21,78% of the simulated trials in case of settling swap contract. 42,70% of the trials will result as a profit.

4.3.5 Pricing of plain vanilla option

Hedging of currency risk by option means that we have right but not an obligation to exercise option. This right is not for free, we have to pay option premium called option price. Option is priced according to Garman-Kohlhagen model Option Pricing Formula. According to (3.37), (3.38), (3.39) and (3.40).

Call option price is given by

$$c = e^{-r_f \cdot dt} \cdot S \cdot N(d_1) - e^{-r_d \cdot dt} \cdot X \cdot N(d_2),$$

put option price is given by

$$p = e^{-r_d \cdot dt} \cdot X \cdot N(-d_2) - e^{-r_f \cdot dt} \cdot S \cdot N(-d_1).$$

Calculation of $N(d_1)$ and $N(d_2)$ which interprets probability that random variable will be lower than d_1 and d_2 is done through function NORMSDIST in MS Excel.

For put option the parameters are following:

- current exchange rate in time t_0, $S_0 = 26{,}47\, CZK / EUR$;
- exercise price $X = 26{,}49\, CZK / EUR$;
- risk-free interest rate of home country $r_d = 2{,}13\%$;
- risk-free interest rate of foreign country $r_f = 1{,}248\%$;
- standard deviation $\sigma = 0{,}01751234$.

If we replace unknowns in figures we will get $d_1 = 0{,}00252769$, $d_2 = -0{,}00252769$, $N(d_1) = 0{,}5010084$ and $N(d_2) = 0{,}4989916$. Price of the put option is $p = 0{,}0729696$ but one option is written on 10000EUR so the final price for 1 option is $p = 729{,}696 CZK$ and when we want to cover 5 million EUR we need 500 options, it means that entering capital requirement is in the level of 364 848CZK.

Total effect from the put option strategy is counted as follows

$$effect_p = Q \cdot g_t - p \cdot q \cdot e^{r_d \cdot T}, \tag{4.8}$$

where g is an intrinsic value.

For call option is than total effect given by

$$effect_c = Q \cdot g_t - c \cdot q \cdot e^{r_d \cdot T}. \tag{4.9}$$

Intrinsic value of call option is counted according to Tab 3.4 as

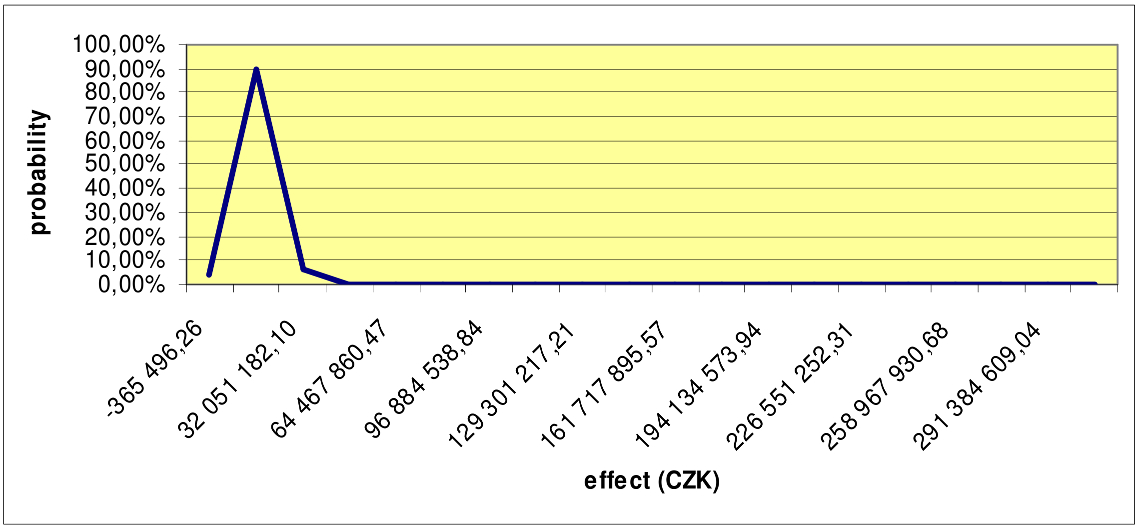
$$g_c = (S_T - X; 0)$$

and intrinsic value of put option is given by

$$g_p = (X - S_T; 0).$$

Probability distribution function for CZK/EUR put option is displayed in the following Figure 4.11.

Figure 4.11: Probability distribution of put option



In case of using put option strategy can the company gain the profit in 96,18% of the cases.

4.3.6 Delta hedging strategy

This strategy of delta hedging uses forward contract. Entering data and the predicted exchange rate are the same as for forward contract.

Firstly we have to count number of forward contracts h for each month according to (3.26). Then we determine price of forward contract and use those values for hedging portfolio calculation. Hedging portfolio is given by (3.23)

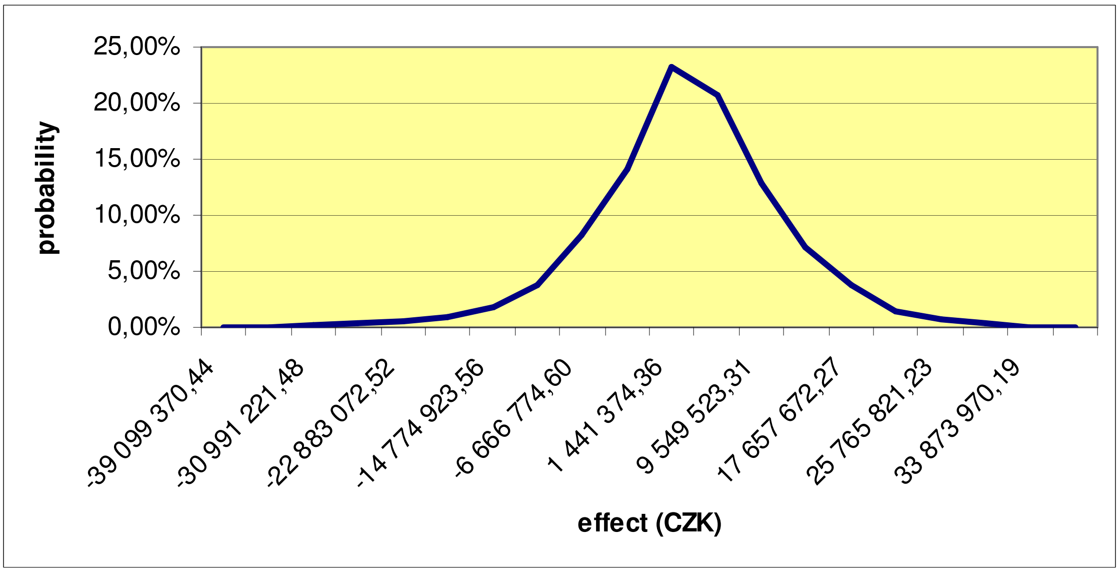
$$\Pi_t = Q \cdot e^{-r_f \cdot (T-t)} \cdot S_t - h \cdot N \cdot f_{t,T}.$$

Effect of this strategy is given as difference between hedged portfolio and unhedged revenue as follows

$$effect_t = \Pi_t - Q \cdot S_t. \qquad (4.10)$$

Figure 4.12 displays profit or loss caused by using this delta hedging strategy.

Figure 4.12: Probability distribution of delta hedging strategy



In case the company enter the delta hedging strategy 70,37% of the cases of simulated rates will end as a profit.

20,80% of all cases is going to be profit in the range from 1 442 thousand CZK till 5 495 thousand CZK.

4.3.7 Risk Reversal

It is type of option strategy where company buys put option and sell call option with the same maturity time, the same underlying asset, the same quantities but with different exercise prices. The company is in position of buyer (put option) and seller (call option) of option so the option premiums may be eliminated and this strategy could be zero-cost.

Exercise price of call option (X_1) should be bigger than exercise price of put option (X_2) and after fulfilling this assumption, the strategy makes sense because when the current spot rate is in space between these two exercise prices, the company is not going to exercise any option. Exercise price of call option (X_1) is settled at the level of 26,7045 CZK. This exercise price is the same for all 12 options. Options are priced according to (3.37) and (3.40).

The input parameters are as follows:

- current exchange rate in time t_0, $S_0 = 26{,}47\,CZK/EUR$;
- exercise price for call option $X_1 = 26{,}7045\,CZK/EUR$;
- risk-free interest rate of home country $r_d = 2{,}13\%$;
- risk-free interest rate of foreign country $r_f = 1{,}248\%$;

- standard deviation $\sigma = 0{,}01751234$;
- quantity of options $Q = 2500000 EUR$.

Exercise price of put option (X_2) is unknown variable for us and it is counted as optimization task through "*Solver*" in the MS Office program where the objective function comes from the assumption that the option premiums are compensated so

$$c - p = 0. \tag{4.11}$$

This task has one constraint as was mentioned before. Exercise price of call option has to be bigger than exercise price of put option hence

$$X_1 > X_2. \tag{4.12}$$

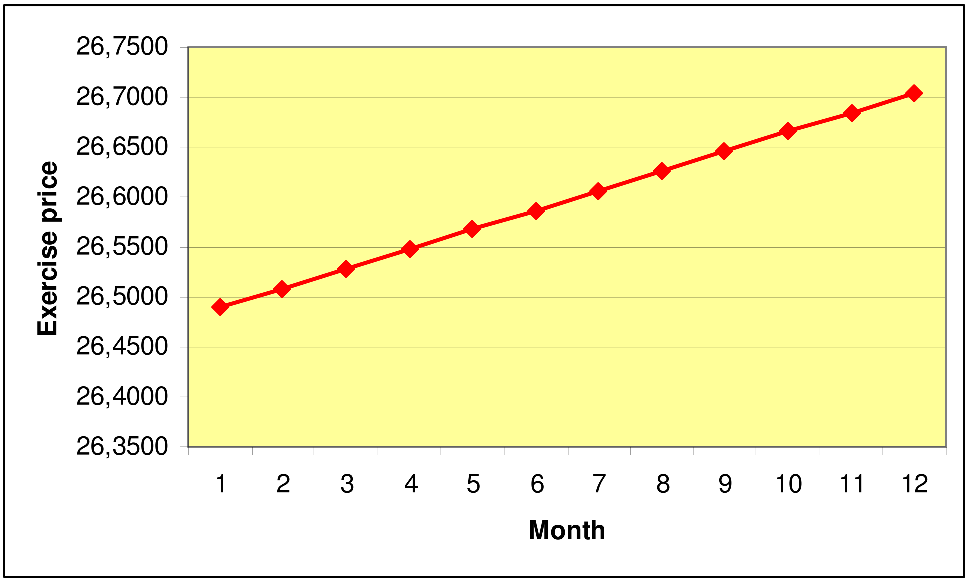
Mathematical formulation is displayed in the Tab 4.3.

Tab 4.3: Mathematical formulation of Risk reversal

Objective function	
$c - p = 0.$	
X_2 is variable.	
Constraints	
$X_1 > X_2$	(P1)
Call and put option are counted as follows	
$c = e^{-r_f \cdot dt} \cdot S \cdot N(d_1) - e^{-r_d \cdot dt} \cdot X \cdot N(d_2),$	(3.37)
$p = e^{-r_d \cdot dt} \cdot X \cdot N(-d_2) - e^{-r_f \cdot dt} \cdot S \cdot N(-d_1).$	(3.40)

Exercise prices of put option for different times to maturity are displayed in the following Figure 4.13.

Figure 4.13: Exercise prices of put option



Following Tab 4.4 displays option premium of put option which is equal to option premium of call option. The only changing factor is time to maturity. We can see that growing the time to maturity is the higher option price is.

Tab 4.4: Put option prices

1	2	3	4	5	6	7	8	9	10	11	12
0,0148	0,0444	0,0693	0,0898	0,1071	0,1220	0,1350	0,1466	0,1570	0,1664	0,1749	0,1826

Effect of the strategy depends on the current spot rate. In case that spot rate S_t is higher than exercise price of call option X_1 we use call option and out effect is following

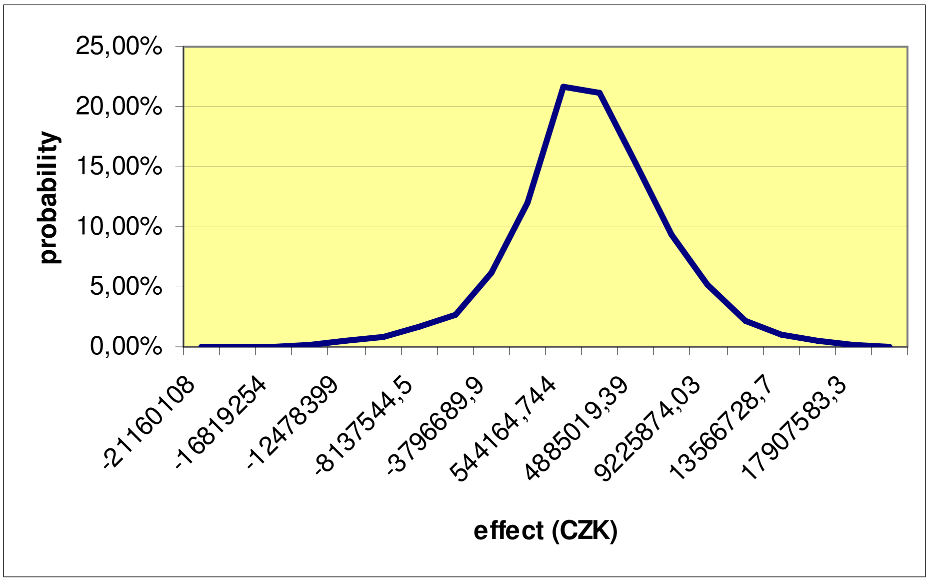
$$effect_t = Q \cdot (X_1 - S_t). \quad (4.13)$$

When the current spot rate is lower than exercise price of put option X_2 we use put option and the effect is following

$$effect_t = Q \cdot (X_2 - S_t). \quad (4.14)$$

Effect from Risk reversal strategy is displayed in the following Figure 4.14.

Figure 4.14: Probability distribution of Risk reversal strategy



This option strategy will bring the profit in 76,20% of all cases. Annual result is for 21,13% of the cases profit with minimum value of 545 thousand CZK and maximum value of 2 714 thousand CZK.

4.3.8 Risk Reversal II.

This strategy is similar to the previous one but some of the entering presumptions are different. Company buys put option and sell call option with the same maturity time, the same underlying asset but with different exercise price and with different quantities.

Changed input parameters:

- quantity of call option $Q_1 = 3000000 EUR$;
- quantity of put option $Q_2 = 2000000 EUR$;
- exercise price of call option $X_1 = 26{,}47\, CZK / EUR$.

Higher quantity of call option underlying asset means better forward rate for the company. Company sells call option in the amount of 3 million EUR and states exercise price at the level of 26,47CZK/EUR. Company wants to buy put option in the amount of 2 million EUR. We need to find value of put option exercise price and values of put options. Exercise price has to be solved through *"Solver"* in a way that both option prices will be compensated so

$$c = p. \tag{4.15}$$

We need to consider different quantities of call and put option and with all the other given parameters we search exercise price of put option X_2 which meets requirement of following formula

$$Q_1 \cdot \sum_{t_i}^{T} c_{t,t_i} = Q_2 \cdot \sum_{t_i}^{T} p_{t,t_i}. \tag{4.16}$$

Mathematical formulation for Risk reversal II. strategy is displayed in the following Tab 4.5.

Tab 4.5: Mathematical formulation of Risk reversal II.

Objective function

$X_2 \rightarrow \max.$

p is variable.

Constraints

$$Q_1 \cdot \sum_{t_i}^{T} c_{t,t_i} = Q_2 \cdot \sum_{t_i}^{T} p_{t,t_i}. \tag{P1}$$

Call and put option are counted as follows

$$c = e^{-r_f \cdot dt} \cdot S \cdot N(d_1) - e^{-r_d \cdot dt} \cdot X \cdot N(d_2), \tag{3.37}$$

$$p = e^{-r_d \cdot dt} \cdot X \cdot N(-d_2) - e^{-r_f \cdot dt} \cdot S \cdot N(-d_1). \tag{3.40}$$

The final value of put option exercise price is $X_2 = 26{,}48946\,CZK/EUR$.

Effect is again dependent on the current spot rate. Quantity of option is different and dependent on the party which exercises an option. In case of Czech crown weakening when spot rate S_t is higher than exercise price of put option X_2 we use call option with the quantity $Q_1 = 3\,million\,EUR$ and out effect is following

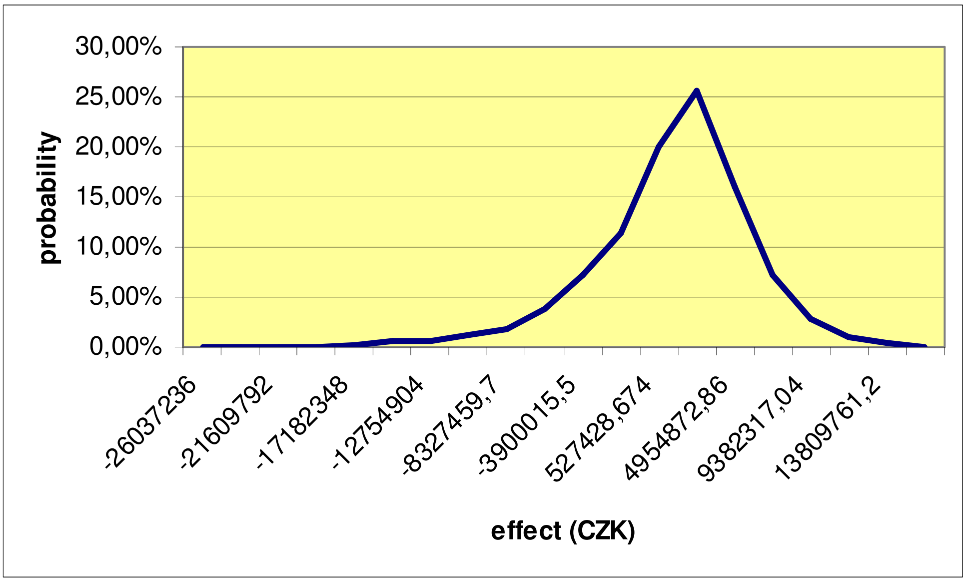
$$effect_t = Q_1 \cdot (X_2 - S_t). \tag{4.17}$$

When the current spot rate is lower than exercise price of call option X_1, it means strengthening of home currency, we use put option with the quantity $Q_2 = 2\,million\,EUR$ and the effect is following

$$effect_t = Q_2 \cdot (X_1 - S_t). \tag{4.18}$$

Effect from Risk reversal II. strategy is displayed in the following Figure 4.15.

Figure 4.15: Probability distribution of Risk reversal II. strategy



If we use Risk reversal strategy where the quantity for call and put option is different than the company can expect profit in 72,97% of the cases. <528 thousand CZK; 2 741 thousand CZK> is the interval for 25,53% of the cases in which the company will gain risk.

4.4 Evaluation of chosen hedging strategies

After all the calculations we are going to evaluate chosen strategies and consider their advantageousness.

4.4.1 Evaluation criteria

Mean value

Mean value expresses average of all values. It is given by

$$E(R_p) = \sum R_t \cdot \frac{1}{N} \tag{4.19}$$

Standard deviation

Standard deviation expresses deviation from the mean value. This deviation represents amount of risk. It is given by function “SMODCH” in the MS Office program.

Quantile 5%

It is counted through function “PERCENTIL” in the MS Office program.

Quantile 50%

50% quantile or in other words median is parameter which divide random variable values in rate 0,5:(1-0,5) where the number 0,5 expresses how much values lies on the left from median. Thus 50% of random variable values are lower than median. It can be counted through function “PERCENTIL” or through “MEDIAN”.

The best result

The best result expresses maximum value of given time line. For maximum value estimation is used function “MAX”.

The worst result

The worst result on the other hand represents minimum value of given time line. Value of this parameter is given by function “MIN”.

Values of observed criteria for single strategies are displayed in the following Tab 4.6 and 4.7.

Profitability of single strategies according to given criteria is expressed by assigned number where 1 is the best result and 8 is the worst result. All criteria are counted from the sum of profit or loss for 12 month of 2010 for all 500 trials.

Choice of the most suitable strategy may be done by several different approaches. In this thesis the most suitable strategy will be chosen according to the investor’s risk attitude, according to combination of returns and risk, then according to entering capital requirements and availability of strategies.

Tab 4.6: Results of observed criteria

	Mean value	Standard deviation	Quantile 50% (median)
Passive strategy	-22 679 993,50 8.	93 233 768,72 6.	-27 367 630,07 8.
Forward maturity 1 month	4 662 412,95 4.	13 025 573,75 1.	5 819 914,11 6.
Forward maturity > 1 month	30 306 161,82 1.	93 233 768,72 6.	34 978 546,06 2.
Swap	-21 025 815,75 7.	93 233 768,72 6.	-25 716 760,67 7.
Put option	4 633 005,49 5.	56 731 428,03 4.	38 999 341,39 1.
Delta hedging	10 997 108,17 3.	82 071 335,87 5.	13 075 442,82 4.
Risk Reversal	13 069 267,32 2.	45 521 804,54 2.	15 134 791,18 3.
Risk Reversal II.	2 867 768,16 6.	45 875 269,71 3.	9 030 870,61 5.

Tab 4.7: Results of observed criteria II.

	Quantile 5%	Min	Max
Passive strategy	-161 465 312,90 8.	-306 513 925,55 8.	274 457 924,41 4.
Forward maturity 1 month	-18 403 719,91 2.	-42 161 576,43 2.	36 224 487,59 8.
Forward maturity > 1 month	-130 846 761,39 6.	-266 847 008,42 6.	314 124 841,54 1.
Swap	-159 814 443,51 7.	-304 863 056,15 7.	276 108 793,81 3.
Put option	-88 733,42 1.	-88 733,42 1.	307 592 948,23 2.
Delta hedging	-129 178 791,44 5.	-265 228 997,30 5.	270 092 876,35 5.
Risk Reversal	-65 423 370,60 3.	-133 423 491,61 3.	153 840 840,82 6.
Risk Reversal II.	-82 373 952,77 4.	-164 288 115,88 4.	122 605 570,22 7.

The most risky strategy is passive strategy. As we can see from the table standard deviation and mean value are the worst parameters from all applied strategies. It means that risk is the highest and return is the lowest. In case of Czech crown strengthening when we consider the worst scenario the company can lose around 300 million CZK. On the other hand in opposite exchange rate evolution the company may gain almost 275 million CZK which is the forth best result. It is strategy only for those investors who are willing to take risk.

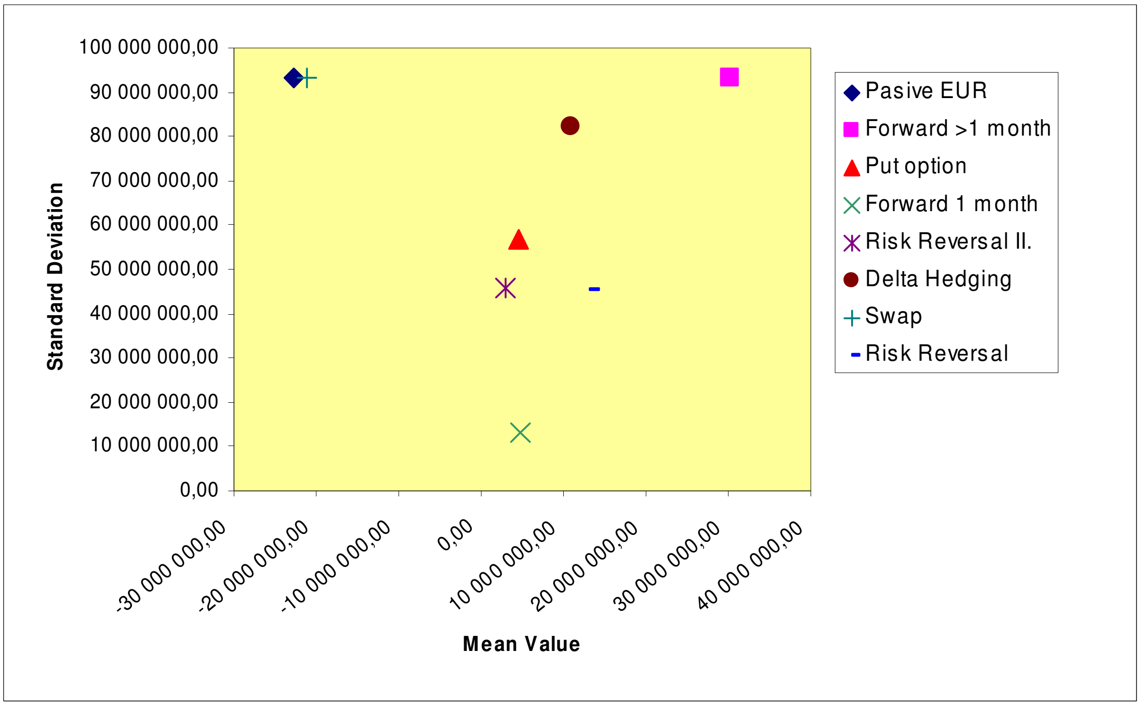
The highest return from hedging strategy can be gained by using forward contract with maturity time longer than 1 month. In case of positive exchange rate evolution the company can gain over 300 million CZK. This return is bounded with high level of risk as well as in case of passive strategy. In comparison with the forward contract which has maturity time 1 month there is not so high profit but risk is significantly lower. Value of standard deviation is the best one from all evaluated strategies.

4.4.2 Evaluation according to return vs. risk combination

Figure 4.15 displays single strategies allocation when we take into consideration mean value and standard deviation combination.

If we consider mutual relation between standard deviation and mean value than it is clear from the figure that the lowest level of risk with the fourth best return is reached by using forward contract with 1 month maturity time.

Figure 4.16: Combination of mean value and standard deviation



If the investor is willing to take some level of risk but not too high, it is good to use one of the option strategies, either Risk reversal II. with different quantities or even better one – Risk reversal with same quantity but different exercise prices of put option X_2. Risk reversal strategy achieves really good results in comparison with the other strategies. In almost all considered criteria is in the second or third place which is very good. This strategy is bounded with average profit of 15 million CZK and with standard deviation on the level of 45 million CZK.

In case that investor wants to put some entering capital into the derivative contract than it is possible to use the put option strategy which, as we can see from the Figure 4.16, is the forth best.

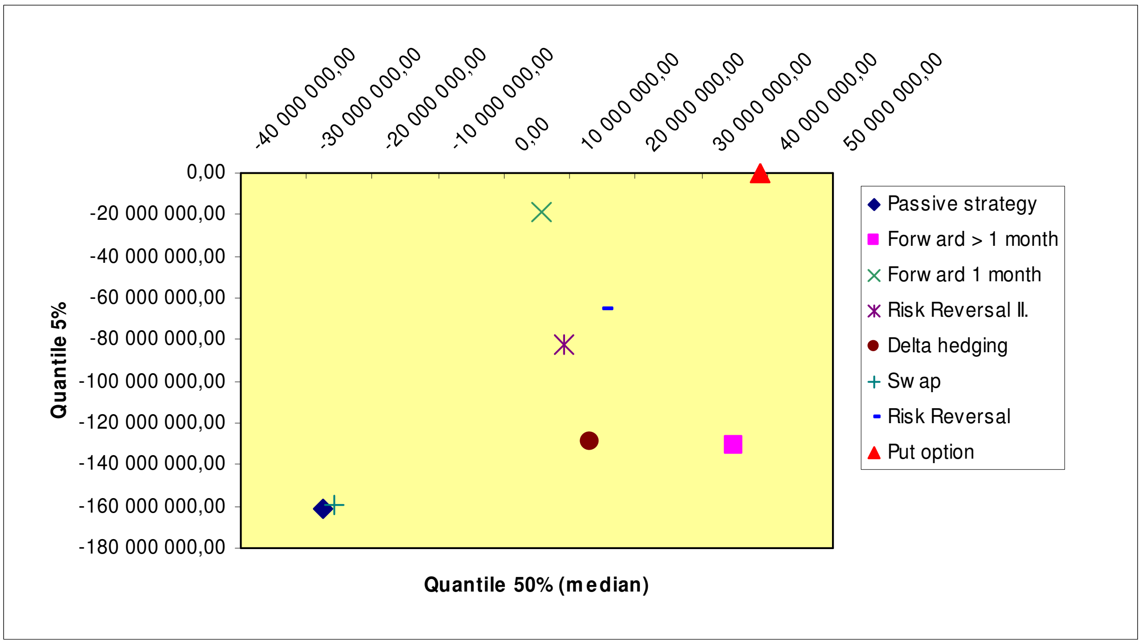
Another way how to evaluate different hedging strategies in terms of risk and revenue combination is to compare relation of two quantiles – 5% and 50% which is median. The results of this comparison can be seen in the Figure 4.17.

In this comparison buying of put option seems to be the best strategy if we compare standard deviation and mean value because the level of risk represented by 5% quantile is the lowest one and the median is the highest one.

Forward contract with maturity time of 1 month seems to be the second best strategy for risk averse investors. Slightly better result in terms of risk is gained in case of Risk reversal option strategy in comparison with the same strategy but with different quantities.

Forward contract with maturity time longer than 1 month is not the worst one because the risk level decreased and from this point of view this strategy seems to be little bit safer as well as Delta hedging strategy.

Figure 4.17: Combination of 50% and 5% quantile



There are four strategies which are not mentioned in this comparison too much or at all. The reason is simple because values of considered criteria are not good for these strategies. Passive strategy is the worst one immediately followed by swap strategy which has only slightly better level of gained revenues. Strategy of delta hedging has better results in case of both considered criteria but it is still bad strategy when we consider all the others. Level of revenue is the second highest one for strategy of forward contract with maturity time longer than 1 month but the level of risk is the highest one so this strategy belongs to the bad ones as well.

4.4.3 Evaluation according to entering capital requirements

Another necessary part of financial management decision making process is money requirement. Because the BorsodChem company prefers strategy with no entering capital requirements we have to exclude plain vanilla put option which is connected with the highest capital requirements. Cost of 1 option written on the amount of 10000 EUR is in January 729,70 CZK and we need to buy 500 options.

Risk reversal and Risk reversal II. are option strategies so we would expect to pay option premiums in the beginning of contract but due to combination of call and put option we are able to nullify the entering requirement. Since there is one option premium we have to pay and one someone has to pay to us by appropriate combination this is zero-cost in the end.

Forward contract strategies, swap strategy and passive strategy does not require any capital in the beginning.

4.4.4 Evaluation according to availability of hedging strategies

We can evaluate given strategies according to their availability for the investor or the company. The easiest strategy from this point of view is passive strategy. This strategy does not require exchange or OTC market because it is not connected with any derivative. Investor can gain pretty high profits but on the other hand the highest loss as well.

The rest of strategies require buying of some derivative either a forward contract or an option. Options are in general more available because there are traded on the OTC and the exchange as well. Forward contracts can be settled only on the OTC market which is not so open to the general public. But because we are considering hedging strategies for BorsodChem company which is big multinational company, there is no problem with availability of derivatives on the OTC market.

4.4.5 Evaluation with respect for all criteria

Every company is making decisions after objective consideration of all factors and criteria not only according to risk level, revenues, entering capital requirements or availability.

If we consider all criteria and point of views on evaluation of hedging strategies we can come to the conclusion. This thesis tended to decrease the level of risk and because we know that BorsodChem company is risk averse investor there is no necessity to gain some high profit, just to hedge the current cash flow of the company with the lowest capital requirements. If we are choosing strategies with lower risk, it means lower standard deviation, then the best choice for the company is

1. Forward with 1 month maturity time and two option strategies
2. Risk reversal and
3. Risk reversal II.

These three hedging strategies are after considering of all criteria chosen as the best ones and the most suitable for the company.

4.4.6 Evaluation of chosen US dollar strategies

Values of observed criteria for single US dollar strategies are displayed in the following Tab 4.8.

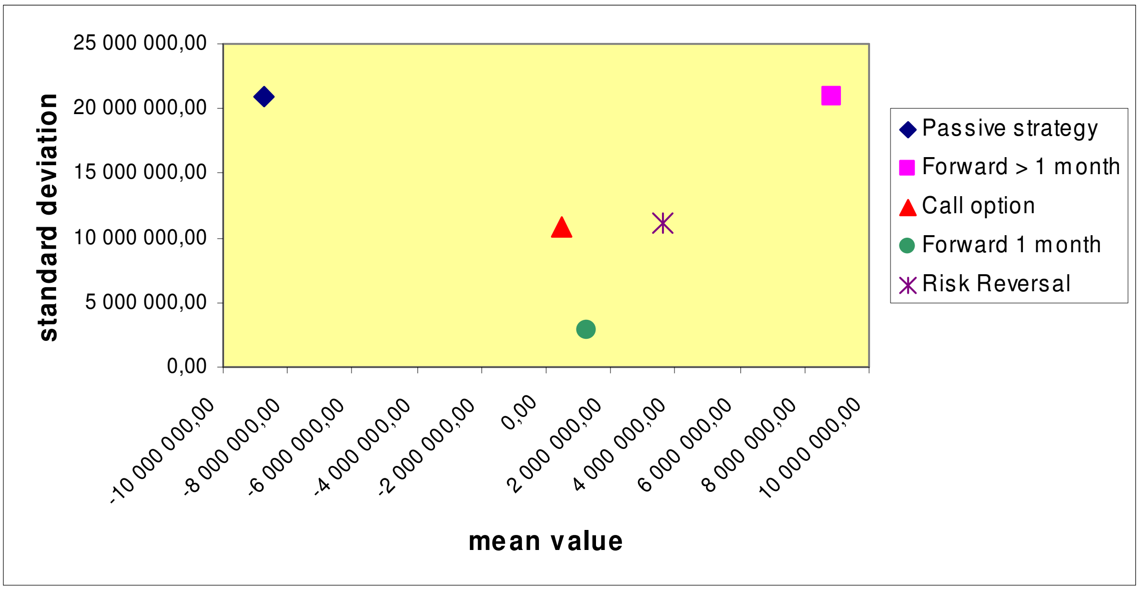
Tab 4.8: Results of observed criteria for US dollar strategies

	Passive strategy	Forward maturity 1 month	Forward maturity > 1 month	Call option	Risk Reversal
Mean value	-8 724 794,44	1 269 700,06 3.	8 856 453,44 1.	463 618,29	3 592 385,89 2.
Standard deviation	20 893 963,48	2 796 937,24 1.	20 893 963,48	10 807 727,62 2.	11 193 801,38 3.
Quantile 5%	-39 756 626,56	-3 737 278,55 2.	-26 842 723,72	-976 348,18 1.	-15 584 508,08 3.
Quantile 50%	-9 867 773,41	1 558 973,74 3.	9 999 169,09 1.	574 406,71	4 585 335,32 2.
Min	-61 809 826,06	-9 871 555,44 2.	-74 034 036,06	-976 348,18 1.	-39 184 126,96 3.
Max	74 165 431,75 2.	8 098 325,65	61 941 221,74 3.	75 250 476,11 1.	31 026 113,03

Explanation is going to be similar as for EUR hedging strategies. The worst strategy is passive strategy with the highest risk level of around 20 million CZK/USD. On the other hand if the investor is willing to take risk then it is almost the best strategy because the maximum value which can be possibly gained is the second best one. But in case of negative evolution there can be high losses.

Figure 4.18 displays all 5 strategies from the risk and return point of view. According to the combination of return and risk is the best strategy forward contract with 1 month maturity which has the best value of standard deviation and the third best value of the mean.

Figure 4.18: Combination of mean value and standard deviation for US dollar strategies



The second strategy which has the lowest level of risk is call option but return of this strategy is not so high. If we take into consideration both variables – risk and return, than better strategy than call option is Risk reversal which has the second best one value of return and the third best one level of risk.

When we consider entering capital requirements we have to exclude call option which requires amount of 74502 CZK in the beginning. The other strategies are not demanding any capital in the time of contract entering.

After consideration of all criteria and factors influencing chosen strategies is the most appropriate strategy buying of forward contract with maturity time of 1 month and as the second one is option strategy Risk reversal.

5 Conclusions

Goal of this thesis was to describe, analyze, verify and apply chosen hedging strategies which can be used for financial hedging in chemical company.

Financial hedging was realized in the BorsodChem MCHZ, s.r.o. company which is company dealing with chemicals. At the first sight there were three possible financial risks – interest rate, commodity and exchange rate. Most of the revenues flows from the foreign countries which means that exchange rate risk is really high and there is need to hedge against unfavourable exchange rate evolution.

Thesis was divided into three parts. First part was aimed at the introduction of the BorsodChem company. There was described history of the company in this chapter but the main expression was laid on business relations, especially costumer and consumer relations and on the research of possible risk factors and their management within the company.

Next part, Chapter 3, is the methodical part in which are explained all the necessary terms such as a financial risk, volatility estimation, an exchange rate forecast, hedging and financial derivatives, such as forward, swap and option.

The most important part is the last one, the practical part of this thesis.

The input parameters for the calculations were the historical data series of monthly exchange rates of CZK/EUR and CZK/USD whose continuous returns were used for volatility estimation by the EWMA model. There was used the Monte Carlo simulation on the basis of Geometric Brownian motion with the logarithmic prices for the future exchange rate evolution. There were simulated 500 trials for 12 steps representing 12 month of 2010. All hedging strategies were dealt with this simulation and the final outputs after the necessary calculations were probability distributions of those trials.

For a currency hedging in the company were chosen and applied following strategies: passive strategy, forward contract with 1 month maturity time, forward contract with maturity time longer than 1 month, swap contract, plain vanilla option contract, delta hedging and two risk reversal strategies with slight differences.

Chosen hedging strategies were after their effect calculation evaluated according to individual criteria which were a mean value, standard deviation, 5% and 50% quantile and minimum and maximum value.

From the point of view of return and risk combination was the best EUR strategy forward contract with 1 month maturity time which had the lowest risk level represented by the standard deviation. The highest return was obtained by using forward contract with maturity time longer than 1 month. When we consider both factors we should use Risk reversal option strategy because mean value and standard deviation are the second best from all strategies.

If the investor wants to have hedging strategy with no entering capital then the put option is not a good choice because it is the most costly strategy. All the other strategies do not require any invested capital.

The most available hedging strategy is passive strategy which does not require any derivative contract. But because the hedging is going to be done by the big multinational company there is no problem in using either option through the exchange or the OTC market or forward contract through the OTC market.

In a case of considering of all criteria and factors is the best strategy forward contract with 1 month maturity time while keeping suitable level of risk and then two option strategies. Risk reversal with the same quantity has slightly better results than the second one.

US dollar hedging strategies came to the similar results. After consideration of all criteria, the best strategy is forward contract with 1 month maturity time. Call option strategy had good results as well but it was excluded because of entering capital requirements. As the second best one was evaluated option strategy Risk reversal.

These chosen strategies represent only part of significant number of ways how to hedge against exchange rate risk. Except the strategies used in this thesis there can by applied another strategies such as several types of exotic options for example binary options – asset-or-nothing or cash-or-nothing, path dependent options – barrier options, asian options or we can use quantile or shortfall hedging. Choice of the strategy depends on the needs of particular subject who is trying to hedge against the risk. In this thesis were used the basic and the most easily available strategies for the BorsodChem company.

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List of abbreviations and symbols

ARCH	- autoregressive conditional heteroscedasticity
a.s.	- stock corporation
CME	- Chicago Mercantile Exchange
CZ	- Czech Republic
CZK	- Czech Crown
ČNB	- Czech National Bank
EBIT	- earnings before interest and taxes
EUR	- Euro
etc.	- an so on
EWMA	- Exponential Weighted Moving Average
FX	- Foreign Exchange
GARCH	- Generalized autoregressive conditional heteroscedasticity
MCHZ	- Moravian Chemical Factory
Nr.	- number
OTC	- Over The Counter
s.r.o.	- Limited Liability Company
USD	- US dollar

Symbols

α	- variable
β	- variable
c	- call option, price of call option
cn	- cash-or-nothing
di	- down-and-in
do	- down-and-out
dt	- time to maturity
dz	- Specific Wiener Process
$E(\cdot)$	- mean value of variable
ε_t	- adjusted returns
$\vec{e}$	- vector
f	- price of derivative
F	- forward rate
g	- intrinsic value
$\ln$	- logarithm
$N(0,1)$	- normal distribution
$N(\cdot)$	- cumulative normal distribution function
p	- put option, price of put option
P	- upper triangle matrix
P_t	- price
Q	- quantity
R_t	- continuous log returns
r_d	- domestic risk-free interest rate

r_f	- foreign risk-free interest rate
S	- underlying asset price
T	- maturity time
t	- current time
ui	- up-and-in
uo	- *up-and-out*
$\mathrm{var}(\cdot)$	
X	- strike price
$\tilde{z}_t$	- random variable
$\rho_{i,j}$	- correlation coefficient
$\sigma_{i,j}^2$	- covariation coefficient
Π	- portfolio
λ	- decay factor
μ	- mean value
$\sigma(\cdot)$	- standard deviation of variable
Σ	- sum
ω	- variable
δ	- delta

List of the figures

Usage of thesis findings statement

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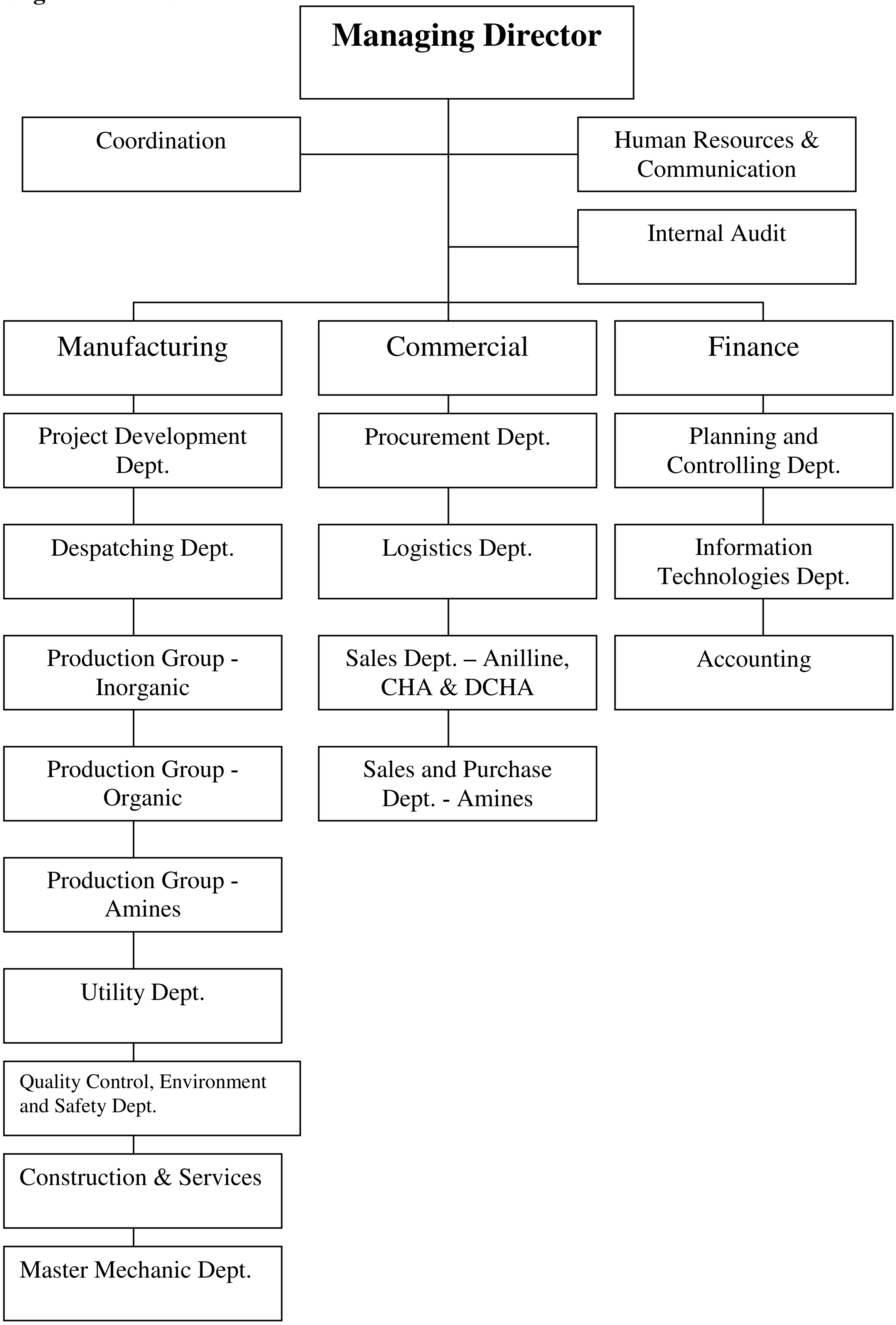
Adresa trvalého pobytu studenta:

………………………………….

Supplements

Supplement 1 – Organisational Structure
Supplement 2 – ICIS pricing of Benzene
Supplement 3 – EUR/USD futures contract from Euronext
Supplement 4 – CZK/USD evolution in 2010
Supplement 5 – USD strategies probability distributions and calculated data

Supplement 1
Organizational Structure



Supplement 2

ICIS pricing of Benzene

Benzene (Europe) 5th January 2010

Editor Madelon Ten Cate

CONTRACT PRICES

Click for Price History			Price Range		USD/GAL
FOB NWE FEB	EUR/MT	-36.00	**723.00-723.00**	-36.00	3.29-3.29
FOB NWE FEB	USD/MT	-83.00	**1012.00-1012.00**	-83.00	3.37-3.37

SPOT PRICES

Click for Price History			Price Range		Four weeks ago	
CIF ARA(*) FEB	USD/MT	-20.00	**995.00-1010.00**	-15.00	1120.00-1130.00	3.31-3.36
CIF ARA(+) FEB	USD/MT	+10.00	**1000.00-1055.00**	-18.00	1113.00-1135.00	3.33-3.51
CIF ARA(*) MAR	USD/MT	n/c	**990.00-1005.00**	n/c	1120.00-1130.00	3.29-3.34
CIF ARA(+) MAR	USD/MT	n/c	**1000.00-1035.00**	n/c	1113.00-1130.00	3.33-3.44

Note: **(*)= Price range at close of business Friday.**
(+)=Price range for the week.

NOTE: For full details on the criteria ICIS pricing uses in making these price assessments visit www.icispricing.com and click on "methodology".

The European February **benzene contract** has settled at **€723/tonne**, down €36/tonne from January, two producers and three consumers confirmed this week.
The settlement was made at a dollar concept of $1,012/tonne FOB NWE, down $83/tonne from January, and converted to the euro price at an officially agreed exchange rate of $1.3999 to €1.

Most players had expected a lower February number after spot benzene values had dropped throughout January in line with **lower energy** numbers, which were down more than $5/bbl since the January contract was agreed, and prices in Asia.

Other reasons for a **bearish** market, sources said, were a stronger US dollar and an ongoing healthy spread of around $400/tonne between naphtha and benzene.

This week, benzene prices were mostly driven by upstream energy movements, although prices in Asia and downstream activity also contributed to some extreme volatility.

The spread between **naphtha** and benzene narrowed to almost $300/tonne on Friday afternoon, which was more realistic than the $400/tonne spread seen between the two products for most of this year.

Activity was **thin** this week, with buying interest from both industry and traders weakening due to a lack of direction. There were no reports of shipments either to the US or to Asia, but one trader said that there would be more exporting opportunities from Asia to the US this month, which would lead to a lack of arbitrage opportunities from Europe.

Indeed, **Asian** traders have been actively trying to export February and March benzene cargoes to the US – a key importer - to get rid of surplus supply, market sources said. So far, about 50,000-60,000 tonnes of shipments have been fixed for loading in February from Asia. For March cargoes, traders said they were finding it difficult to fix cargoes due to rapid fluctuation in crude values and in inter-regional prices of benzene.

It was uncertain how the holiday season in Asia would affect European activity. For the moment, March was talked in a backwardation of between $10-25/tonne during the week, but players expected this to narrow as the end of the month came closer.

Some players in Asia expected benzene prices in the region to remain weak, in line with softening crude values and high benzene supply.

On the **spot market** in Europe, the week closed more or less where it opened at around $1,000/tonne, despite mid-week hikes of more than $50/tonne, which were mainly driven by crude movements.

February deals were done at $1,005/tonne in the beginning of the week, but later rose to $1,045-**1,055/**tonne mid-week. On Thursday, prices fell again and several deals were done at **$1,000**-1,020/tonne.
A **March** deal was done at **$1,000/**tonne early in the week, spiking to $1,025-**1,035/**tonne mid week. On Thursday, a final deal was done at $1,005/tonne after which the market remained quiet.
On the basis of deals done, the weekly February range was pegged at **$1,000-1,055/tonne** and the March range at **$1,000-1,035/tonne.**
By the close of business, February was talked at **$995-1,010/tonne** and March at **$990-1,005/tonne.**

($1 = €0.73)

Supplement 3

Euro/US dollar futures contract from Euronext

Codes and classification

Mnemo	FED	Market	NYSE Liffe Amsterdam	Vol.	26 01/03/10
		Currency	$	O.I.	147

Euro / US Dollar Futures	
Unit of trading	€20,000
Expiry months	1) Initial lifetime: 1, 2 and 3 months. Cycle: all months 2) Initial lifetime: 6, 9 and 12 months. Cycle: March, June, September and December
Quotation	In US dollars per EUR 100 (USD 0.01 represents USD 200 per contract)
Minimum price movement (tick size and value)	USD 0.01 (USD 2)
Last trading day	13.00 Amsterdam time on the third Friday of the delivery month, provided this is a business day. If it is not, the previous business day will be the last day of trading.
Settlement	Cash settlement, based on the value of the euro / US dollar rate set by EuroFX at 13.00 Amsterdam time. For FDE, the inverse value of the EuroFX euro/Us dollar rate is used and rounded off to four decimal places.
Trading hours	9.00 – 17.30 Amsterdam time
Clearing	LCH.Clearnet S.A.
Last update	21/09/07

Euronext.liffe Market: Amsterdam

Trading Platform:

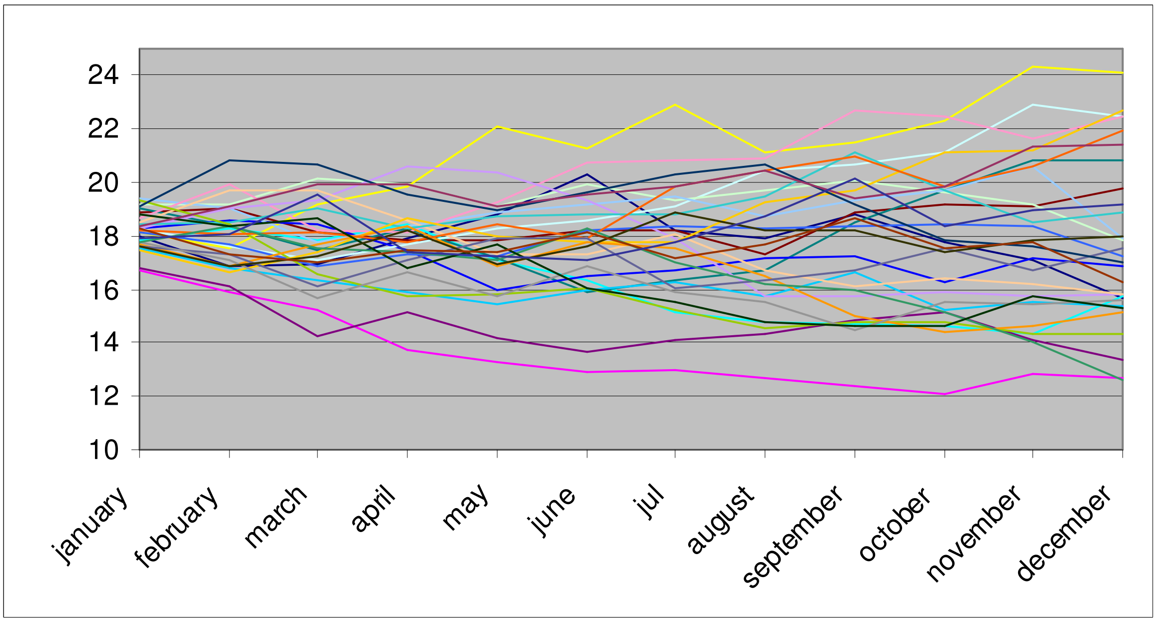
- **Trading Platform:** LIFFE CONNECT® Trading Host for Futures and Options
- **Wholesale Service:** Prof Trade Facility

Unless otherwise indicated, all times are Amsterdam times.

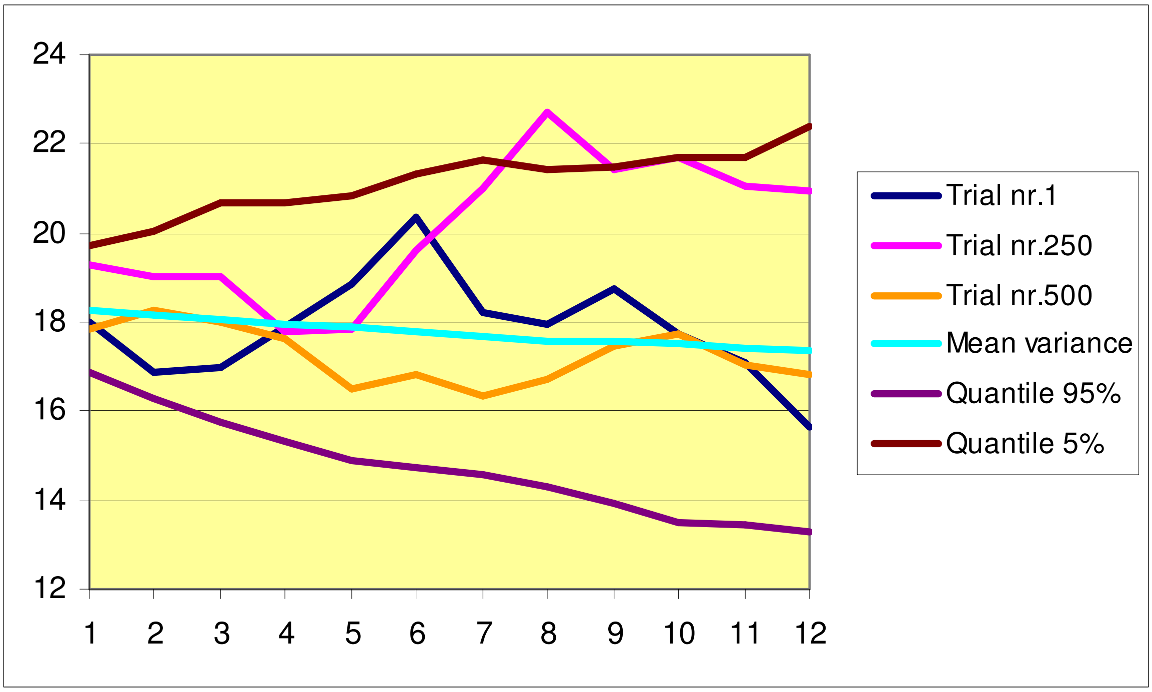
Supplement 4

CZK/USD forecast for 2010

CZK/USD evolution in 2010



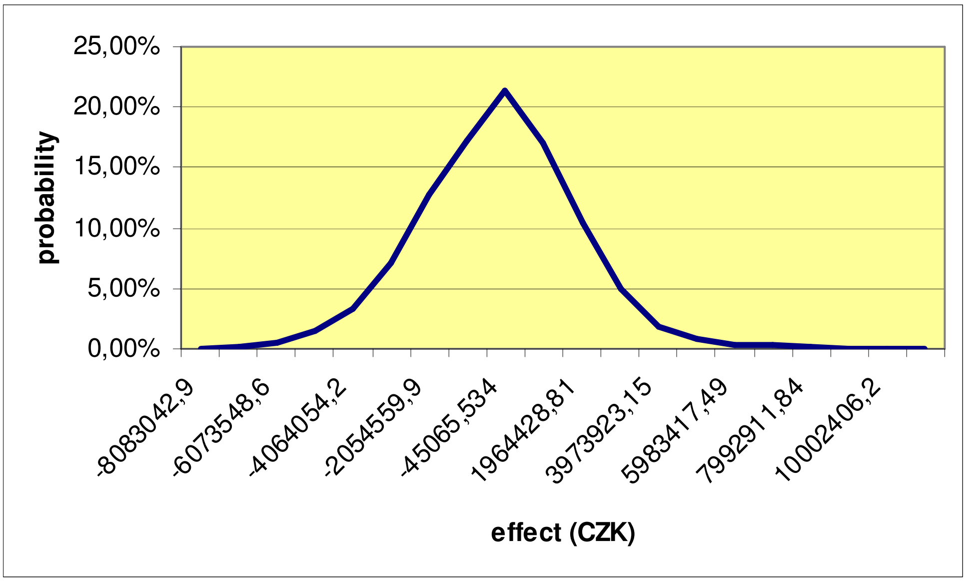
Random exchange rate CZK/USD evolution



Supplement 5

USD strategies probability distributions and calculated data

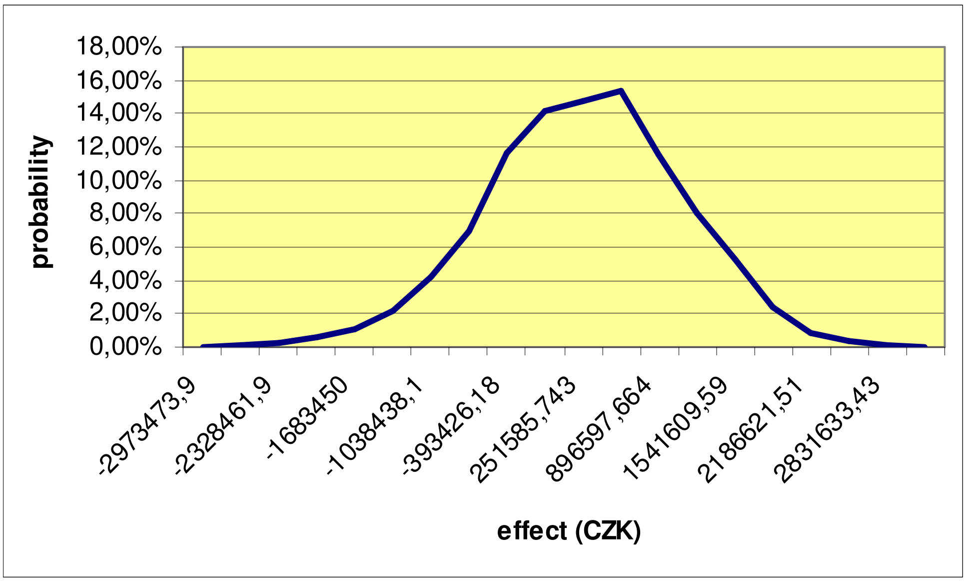
Figure A: Passive strategy



Tab A: Calculated data for passive strategy

	Pasive USD
Mean value	-8 724 794,44
Standard deviation	20 893 963,48
Quantile 5%	-39 756 626,56
Quantile 50%	-9 867 773,41
Minimum value	-61 809 826,06
Maximum value	74 165 431,75

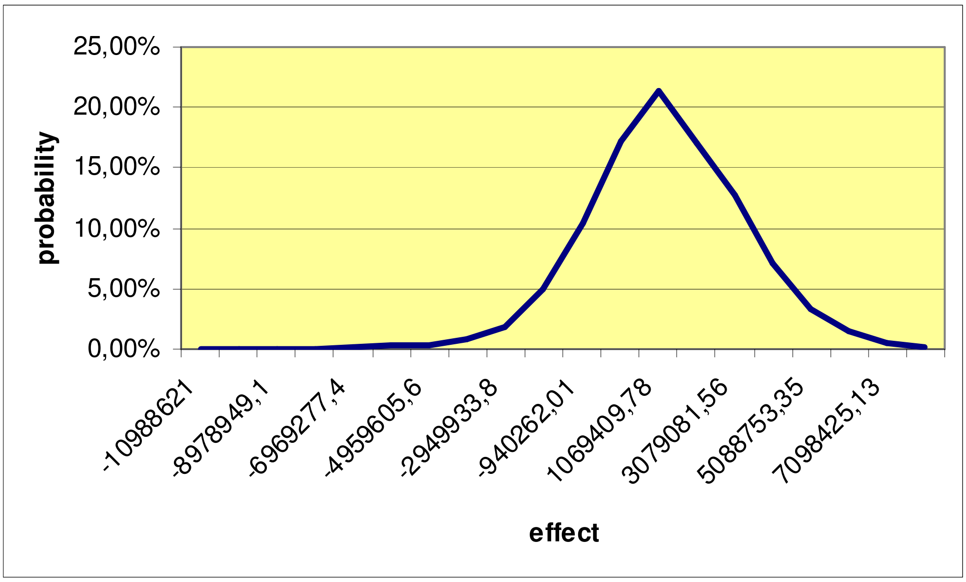
Figure B: Pricing of forward with 1 month maturity



Tab B: Calculated data for forward with 1 month maturity

	Forward maturity 1 month
Mean value	1 269 700,06
Standard deviation	2 796 937,24
Quantile 5%	-3 737 278,55
Quantile 50%	1 558 973,74
Minimum value	-9 871 555,44
Maximum value	8 098 325,65

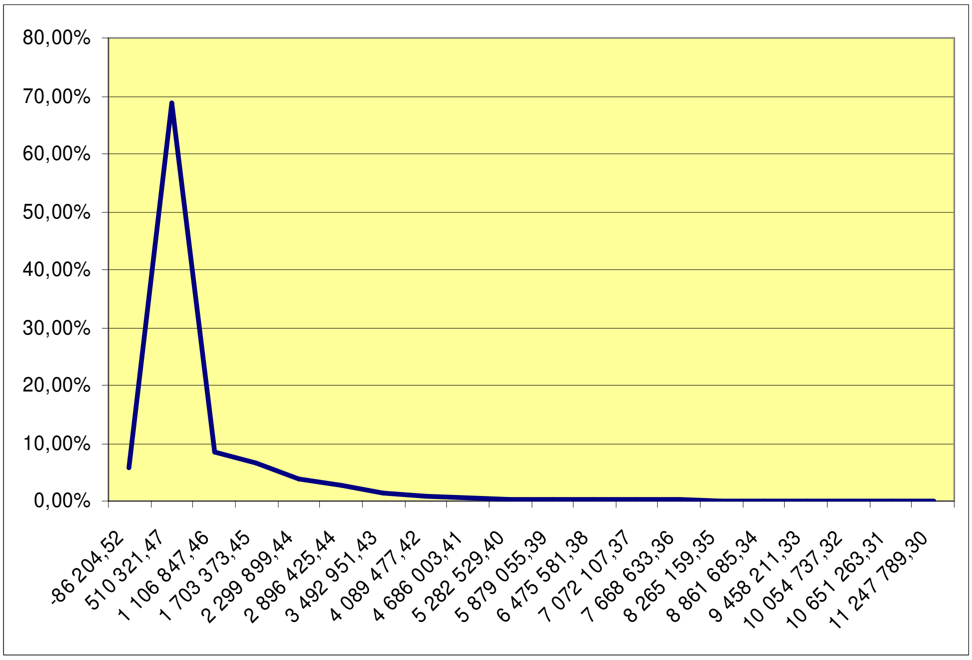
Figure C: Pricing of forward with longer maturity time



Tab C: Calculated data for forward with longer maturity time

	Forward maturity > 1 month
Mean value	8 856 453,44
Standard deviation	20 893 963,48
Quantile 5%	-26 842 723,72
Quantile 50%	9 999 169,09
Minimum value	-74 034 036,06
Maximum value	61 941 221,74

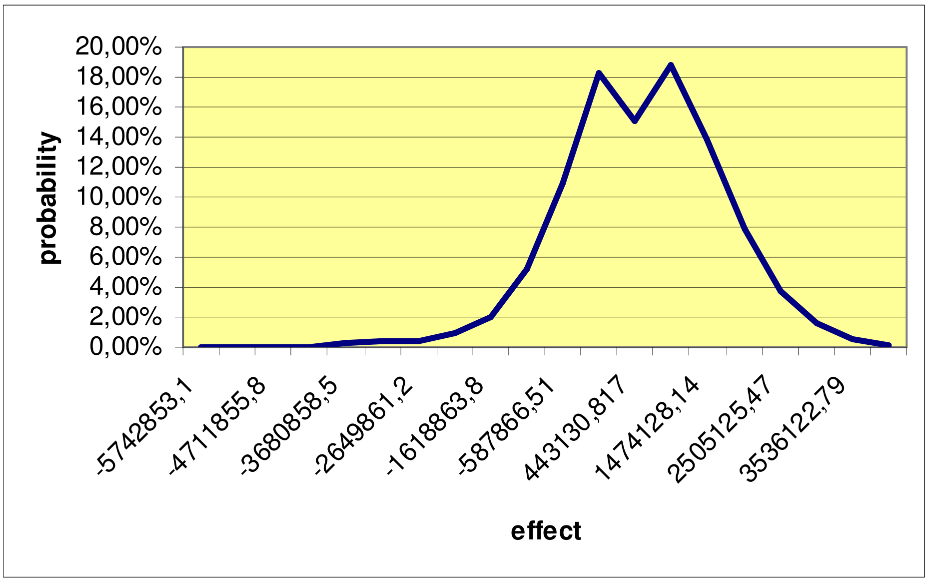
Figure D: Pricing of plain vanilla call option



Tab D: Calculated data for plain vanilla call option

	PV call USD
Mean value	463 618,29
Standard deviation	10 807 727,62
Quantile 5%	-976 348,18
Quantile 50%	574 406,71
Minimum value	-976 348,18
Maximum value	75 250 476,11

Figure E: Pricing of Risk Reversal strategy



Tab E: Calculated data for Risk Reversal strategy

USD	Risk Reversal
Mean value	3 592 385,89
Standard deviation	11 193 801,38
Quantile 5%	-15 584 508,08
Quantile 50%	4 585 335,32
Minimum value	-39 184 126,96
Maximum value	31 026 113,03